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IMPACTS OF THE OPERATION OF EXISTING HYDROELECTRIC DEVELOPMENTS ON FISHERY RESOURCES IN BRITISH COLUMBIA

VOLUME I

ANADROMOUS SALMON

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IMPACTS OF THE OPERATION OF EXISTING HYDROELECTRIC DEVELOPMENTS ON FISHERY RESOURCES IN BRITISH COLUMBIA

VOLUME I

ANADROMOUS SALMON

by

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ABSTRACT

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B.C. Hydro operates 25 dams and diversions on 16 British Columbian rivers which support anadromous salmon. Impacts on salmon vary according to the degree of flow regulation, the operating mode of the plants and the extent of downstream habitats and populations. Most frequently recorded impacts include low flows restricting spawning migrations and mainstem spawning and rearing; high water temperatures in summer; flooding and sedimentation causing loss of eggs, rearing fry and habitats; fluctuating water levels leading to stranding and exposure of fry and eggs; migrating spawners being delayed at powerhouse tailraces or dam spillways; and smolt and fry mortalities occurring during passage through powerhouse turbines. The quantitative and/or economic extent of these impacts has seldom been determined.

Six of the 25 dams or diversions have requirements for flow releases written into the conditional water licences, while agreements on water releases have been negotiated for an additional four. Releases are usually set at or close to the minimum monthly flows and fall far short of that needed for sustained salmon production. There has been little follow-up or monitoring to check on the value of releases. Some regulated rivers have incurred impacts not directly related to hydroelectric regulation, e.g. urban encroachment and/or gravel removal.

Three installations (Seton Creek, Puntledge and Quinsam) have specific water release schedules and/or operational constraints based on studies, observation and trial and error; these have improved conditions for migrating and spawning salmon. Informal agreements on water releases are in effect for an additional seven plants (Coquitlam, Alouette, Stave, Wahleach, Shuswap, John Hart and Cheakamus); the benefits of these arrangements to the salmon resources are not yet documented.

Existing knowledge of most regulated salmon-bearing rivers is inadequate to permit an estimation of the amount of improvement to be gained by improving flow conditions. Escapements, spawning success, egg-to-fry survival rates, adult return percentages and other production parameters are affected by multiple factors, many of them far removed from the river system being managed. Accuracy and reliability of escapement counts used to measure the strength of salmon stocks in regulated rivers are often questionable.

RESUMÉ

Hirst, S.M. 1991. Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia. Volume I. Anadromous salmon. Can. Manuscr. Rep. Fish. Aquat. Sci. 2093: 144p.

B.C. Hydro exploite 25 barrages et dérivations sur 16 cours d'eau de la Colombie-Britannique où évolue le saumon anadrome. Les effets sur le saumon varient selon le degré de régularisation du débit, le mode d'exploitation des centrales et la quantité d'habitats et de populations en aval. Les effets les plus fréquemment signalés sont les faibles débits qui réduisent les migrations reproductrices de même que la fraie et l'alevinage dans le tronçon principal; les températures élevées en été; les inondations et la sédimentation qui occasionnent la perte des oeufs, des alevins en croissance et des habitats; le retard de migration des géniteurs au niveau des canaux de fruite des centrales ou des déversoirs des barrages et la mort des smolts et des alevins lorsqu'ils traversent les turbines des centrales. L'aspect quantitatif ou économique de ces effets a rarement été déterminé.

Des normes d'apport d'eau sont stipulées dans les permis conditionnels d'exploitation hydrauliques de six des 25 barrages ou dérivations et des ententes en matière d'apport d'eau ont été conclues dans le cas de quatre autres. Les apports d'eau sont habituellement fixés au débit mensuel minimum ou à peu près et sont très en deça des débits requis pour une production soutenue de saumons. Il y a peu de suivi ou de surveillance pour déterminer la valeur de ces apports d'eau. Certains cours d'eau dont le débit est régularisé subissent des effets qui ne sont pas directement reliés à l'exploitation hydroélectrique, mais à la prolifération urbaine ou à l'enlèvement du gravier.

Trois installations (Seton Creek, Puntledge et Quinsam) ont des calendriers spécifiques d'apport d'eau ou des contraintes opérationnelles fondées sur des études, des observations ou des essais empiriques; ces installations ont amélioré les conditions de migration et de fraie des saumons. Il y a des ententes officieuses concernant l'apport d'eau avec sept autres centrales (Coquitlam, Alouette, Stave, Wahleach, Shuswap, John Hart et Cheakamus); les avantages que représentent ces ententes pour les saumons ne sont pas encore connus.

Les données dont nous disposons actuellement sur la plupart des cours d'eau salmonicoles régularisés ne sont pas suffisantes pour nous permettre de calculer le degré d'amelioration fourni par la modification du débit. Divers facteurs influencent les échappées, la fraie, le taux de survie oeuf/alevin, le pourcentage de retour des adultes et

d'autres paramètres liés à la production du saumon et nombre de ces facteurs sont très éloignés des cours d'eau régularisés. On peut souvent douter de l'exactitude et de la fiabilité des données concernant les échappées, qui servent à mesurer l'abondance des stocks de saumon dans les cours d'eau régularisés.

PREFACE

This report reviews the known impacts of B.C. Hydro's hydroelectric projects on anadromous salmon resources and is based on information and data drawn from management reports, memoranda, minutes of technical meetings, correspondence and discussion with personnel from B.C. Hydro, the Department of Fisheries and Oceans and the B.C. Ministry of Environment. Some data are incomplete or preliminary in nature. Further detailed investigations of specific river systems can be expected to improve the understanding of impacts and the opportunities available to improve salmon resources in regulated systems. B.C. Hydro and the Department of Fisheries and Oceans concur with the facts presented on the various hydroelectric projects and the documented impacts on anadromous salmon resources. The conclusions and recommendations presented are those of the author and not necessarily those of B.C. Hydro or the Department of Fisheries and Oceans.

INTRODUCTION

Hydroelectric power generation is the most important source of electricity in British Columbia, partly because of relatively low costs per unit electricity produced and partly because of the abundance of potential hydroelectric sources in the province. Hydroelectric development commenced in B.C. in 1898 and is today responsible for more than 95 percent of all electricity generated (B.C. Hydro 1987). About 85 percent of the total generating capacity in the province is controlled by B.C. Hydro.

With the exception of the Columbia River watershed, most Pacific drainages in B.C. which have been impounded for hydroelectric power generation contain anadromous salmon resources. Hydroelectric power generation can impact salmonid fishery resources in a number of ways, including decreases in wetted areas, fluctuating flows, sedimentation, blocked access, water temperature alterations, gas supersaturation and reduced capacity to assimilate pollutants (Burt and Mundie 1986). Some of these effects have already been documented to occur in B.C. Hydro-regulated systems such as the Campbell and South Alouette rivers (Burt and Mundie 1986). Most of the B.C. hydroelectric installations now operating on rivers inhabited by anadromous salmonids were constructed before the advent of progressive environmental assessments and present-day attitudes towards resource development and conservation.

Attempts to restore and enhance salmonid habitats damaged by upstream hydroelectric impoundment and operations face two important issues. Firstly, impacts of hydroelectric power generation on habitats in the Pacific region vary considerably due to differences in geography, size and morphology of river systems, size and conformation of the hydroelectric development, and the present and potential value of the salmon habitats. The likelihood of successful restoration and improvement through operational changes, engineering improvements or other forms of habitat enhancement varies accordingly between developments. Secondly, restoration of salmon habitats and populations below power dams would vary in cost-effectiveness according to the intrinsic value of the resource and the extent of the restoration measures required.

This report aims to provide a basis for improved management of the salmon resource in rivers affected by hydroelectric regulation in B.C. Specifically the report's objectives are to:

a. review the status of hydroelectric developments operated by B.C. Hydro and their impacts on anadromous salmon resources;

b. review the adequacy of existing flow regimes for maintaining downstream salmon habitats and populations;

c. determine the potential for improving anadromous salmon habitats and populations in B.C. Hydro-regulated river systems;

d. provide recommendations on how the existing situation in general and for specific installations might be improved.

The review mainly addresses impacts to anadromous Pacific salmon - sockeye (*Oncorhynchus nerka*), chinook (*O. tshawytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*) and chum (*O. keta*). Impacts of hydroelectric operations on B.C. inland fisheries are reviewed in Hirst (1991).

METHODS

All the information contained in the review was taken from existing sources. Field surveys of the river systems in question were not undertaken.

Information on the hydroelectric dams and generating stations in B.C. was provided by the Operations Control Department of B.C. Hydro and the Water Management Branch of the B.C. Ministry of Environment (MOE). The latter department also provided information on water licences applicable to the hydroelectric installations. A total of 18 B.C. Hydro hydroelectric plants are sited either on salmon-bearing rivers or on marine inlets used by salmon (Figure 1). Two plants - Clayton Falls and Clowholm - are located on arms or channels of marine inlets immediately below steep falls which are impassable to anadromous salmon. The report deals with the remaining 16 hydroelectric plants.

Data on the salmon resources of the respective river systems were taken from stream information summaries developed by the Fish Habitat Inventory and Information Program, and supplemented by literature and data searches in libraries of the Department of Fisheries and Oceans (DFO) and the Recreational Fisheries Branch of MOE. Current and archived files of DFO dealing with each regulated river system were searched for information and relevant data. Data on salmon escapements were taken from escapement and spawning records held by DFO in Vancouver.

Data on water flows in the regulated river systems were taken from stream flow summaries provided by the Water Survey Branch of the Inland Waters Directorate and from monthly operational summaries for the various generating plants provided by B.C. Hydro.

Data and information held in the regional offices of DFO and MOE in the various regions and sub-districts of the province were not accessed. Personal communications were received from a number of regional biologists, fisheries officers and hatchery managers on flow requirements and existing conditions in regulated systems.

Sources of the information and data used in the study are given in the References section. To reduce repetition and enhance readability the acronym DFO is used to refer to the present Department of Fisheries and Oceans as well as the Department of Fisheries, the Fisheries and Marine Service and various other designations used in the past. The acronyms IPSFC refer to the International Pacific Salmon Fisheries Commission and SEP to the Salmonid Enhancement Program of DFO.

COQUITLAM RIVER

PROJECT

Description

The project consists of a 30 m high, 300 m long, earthfill dam across the Coquitlam River, approximately 16 km above its confluence with the Fraser River (Figure 2). The dam is equipped with an overflow weir of 500 m^3/s capacity, a large gated sluice tunnel, and a separate outlet for the Greater Vancouver Regional Water District (GVRD) supply. A 4 km power tunnel leads water to Buntzen Lake from where power flows are directed to the Buntzen generating stations on Indian Arm. Total nameplate generating capacity of the stations is 76.7 MW. Total storage of Coquitlam Lake is 222 million m^3. There are no fish passage facilities at the dam. Coquitlam Dam was constructed in 1914 (Vancouver Power Company) and rehabilitated in 1980 (B.C. Hydro).

Water Licences and Operational Constraints

The water licence entitles the holder to total storage of about 3.2 billion m^3, and maximum diversion of 82 m3/s. A separate water licence is held by the GVRD Water District for drinking water removal from the reservoir. There are no provisions in the licence(s) for any releases for fishery needs. Total licensed withdrawals are about 3 m^3/s more than the mean annual inflows to Coquitlam Lake (Water Investigations Branch 1978).

Electrical Generation

No power is generated at the dam site. The flows from Coquitlam Lake are directed to Buntzen Lake from where power flows are drawn by the Buntzen generating stations. These plants operate as auxiliary and peaking plants. From 1984 to 1987, Buntzen generated from zero to 28.4 million kWH per month (52 percent of capacity). Generation in most months was from 20 to 40 percent of capacity.

Enhancement Facilities

No facilities are associated with the hydroelectric project. Local conservation groups maintain coho and trout incubation boxes along the upper tributaries.

FLOW REGIME

Pre-impoundment discharges of the Coquitlam River were not gauged. The mean annual inflow to Coquitlam Lake is estimated at about 35 m^3/s, while the mean annual flow in the lower Coquitlam River (derived mainly from tributaries such as Scott and Hoy creeks) from 1968 through 1984 was 5 m^3/s (Inland Waters Directorate 1988). The discharge regime of the Coquitlam River below the impoundment is highly variable (Figure 3) with most variation coming from flood flows from the upper tributaries. Mean and minimum flows are more constant. Flows in August and September are typically very low (Figure 4).

HABITATS

Below Impoundment

From 1949 to 1965 extensive gravel removal took place in the lower and mid-sections of the river, much of it accompanied by channelling (Marshall et al 1979). Additional bed and shoreline impacts were caused by diking and flood protection works. The overall results were channel confinement, an increase in gradient, unstable river bottom, and a tremendous increase in silting. Bank slides due to instability are common. There is a considerable inconsistency in the existing gravel substrates due to flooding, gravel extraction and bed instability, and a severe depletion of biological productivity. Gravel removal has continued to date, although at a lesser intensity (Ross et al. 1985). Gravel removal operations adjacent to the river have continued and run-off entering the Coquitlam River contains high proportions of silt at times (DFO, pers. com.)

Tributaries to the Coquitlam still contain useful habitats for coho and steelhead and cutthroat trout, but are being increasingly impacted by urbanization (De Leeuw 1982).

Above Impoundment

Coquitlam Lake is presently inaccessible to anadromous salmon and is likely to remain so within the confines of the existing water management regimes for power and drinking water.

SALMON POPULATIONS

Historic Populations

There are no records of sockeye or chinook salmon occurring in the Coquitlam watershed, although initial dam construction probably blocked sockeye salmon access to Coquitlam Lake (DFO, pers. com.). Coho, pink and chum salmon escapements of several thousands each have been recorded in the past (see below), but there is no evidence that the river historically was a major production area for salmonids, one possible reason being the highly variable nature of the discharges, and the likely high incidence of flooding in pre-impoundment periods.

Escapements

Coho escapements to the Coquitlam River have ranged up to 1000 for the period over which such data have been collected (Figure 5). The declines in stocks through the 1950's and 60's may have been correlated with the incidence of instream gravel mining, channelling and urbanization. Coho have persisted in the system due to the availability of habitats in the tributaries and propagation by local conservation groups. Pink salmon escapements declined sharply following the advent of gravel extraction operations, and dropped from highs of 1500-2500 to near zero by 1957. Chum salmon escapements have historically varied from as low as 300 to about 7500 but have also declined markedly since 1950 to stabilize at about 1000.

Spawning and Rearing

Coho move up into the mainstem river and the larger tributaries from October through January and spawn on arrival (Graham et al. 1977). Prior to their decline, pink salmon spawned in October and November of odd-numbered years. Their spawning areas were confined to the low gradient sections of the lower river. Fry emerged in May and migrated directly out of the system. Chum salmon also spawn in the lower reaches only, from October through November. Fry emergence for each of the three salmon species in the system takes place in May, but coho emergence extends through until June. Coho juveniles remain in the river for a year before moving into the Fraser River (De Leeuw 1982) while pink and chum salmon fry move directly out to the Fraser River following emergence (Graham et al. 1977).

PROJECT OPERATIONAL IMPACTS

Salmon habitats within the Coquitlam River have been extensively impacted and degraded as a result of gravel extractions, channelling, siltation, urbanization and associated impacts (Marshall et al 1979). The effects of hydroelectric impoundment are additive to these.

Summer Low Flows

Flows from mid-July to the end of October are judged to be limiting to severely limiting to rearing coho juveniles in most years (Graham et al. 1977). Flows during this period typically average about 0.7 m^3/s and can drop to as low as 0.03 m^3/s, as gauged in the lower Coquitlam River (Water Survey flow data). Supplementing of flows in the summer period was recommended in the watershed management plan for the Coquitlam River (Water Investigations Branch 1978), but has apparently not been implemented to date. B.C. Hydro has in the past, at the specific request of DFO, released water from Coquitlam Lake (up to 2.5 m^3/s) for short periods for fisheries protection purposes, but there is no consistent water release program. Low-level valve leakage at the base of the dam provided small but important quantities of water for rearing juvenile salmon through the summer periods for a number of years, but has now been repaired (DFO, pers. com.)

Water Temperatures

Critically high water temperatures accompany low flows in late summer (Graham et al. 1977, De Leeuw 1982). During these periods temperatures can reach 25° C for intermittent periods.

SALMON MANAGEMENT REQUIREMENTS

The water licences for the Coquitlam development were issued at a time when little concern for water shortages below the impoundment was evident, and consequently no provision exists in the licences for release for fisheries or other purposes (other than GVRD drinking water supplies). B.C. Hydro has occasionally released water for short periods to comply with specific requests from DFO (e.g. sediment flushing) but is reluctant to do so on a continuing basis. The underlying reasons for this reluctance appear to relate to a number of issues, including a concern for setting a precedent for demands from other potential users downstream, the economic value of the water when converted into electric generation potential, and the poor habitat quality of the downstream reaches due to gravel extraction and urban impacts.

The Coquitlam watershed management plan (Water Investigations Branch 1978) was intended as a device for integrated planning and management of the watershed, but has not to date proven effective in this regard. Implementation of salmon restoration and enhancement in the system would involve a two-stage process:

a. reducing or hopefully eliminating the serious problem of habitat degradation due to gravel extraction and urban encroachment, and

b. developing an improved summer flow regime in the lower Coquitlam.

SOUTH ALOUETTE RIVER

PROJECT

Description

The Alouette Dam was constructed in 1926 (Burrard Power Company) at the outflow of the South Alouette River and rehabilitated by B.C. Hydro in 1983. Alouette Lake was converted into a reservoir with a surface area of 1600 ha and storage of 209 million m^3. The dam is a 20 m high, 315 m long, earthfill structure with a concrete overflow weir, three vertical lift gates and a low level outlet port. A power tunnel less than 1 km in length leads from the northern end of the lake to Stave Lake (Figure 6). A small generating plant of 8 MW capacity operates at the outlet of the tunnel on Stave Lake, and flows are then passed into Stave Lake and through the Stave Falls (52.5 MW) and Ruskin (105.5 MW) generating plants.

Water Licences and Operational Constraints

In 1923 the B.C. Electric Company was granted a licence for diversion of 20 m^3/s (700 cfs) from Alouette Lake to Stave Lake. In 1929 they were granted right to an additional 8.5 m^3/s (300 cfs) diversion. The final water licences, dated 1929, permit storage of 186 million m^3 and a total diversion of 28 m^3/s (1000 cfs). There are no provisions for water releases for fisheries or any other purposes.

In 1971 B.C. Hydro undertook to maintain a minimum flow of 0.7 m^3/s (25 cfs) in the S. Alouette River as gauged at 232 Street, which meant a minimum release of about 0.06 m^3/s (2 cfs) continuously through the low level outlet. This agreement is still in effect, although the actual amounts released since August 1986 have ranged from 0.17 m^3/s (6 cfs) to 1.2 m^3/s (43 cfs) (B.C. Hydro, Operations Control Department, flow release data).

Electrical Generation

The generating plant at the outlet of the power tunnel on Stave Lake generates power when flows are released from Alouette Lake. In the period from January 1984 through June 1987 the plant operated in only 7 months out of 42, with generation ranging from near zero to 5.2 million kWH per month (about 90 percent of capacity). The Alouette plant contributes less than 0.1 percent, and Stave Falls and Ruskin together contribute from 1 to 3 percent, of B.C. Hydro's total monthly hydroelectrically derived power.

Enhancement Facilities

No enhancement facilities are associated directly with the hydroelectric installation. The Haney Correctional Institute, located on the mid-section of the S. Alouette River maintains both incubation and rearing boxes; coho are reared to the smolt stage and released back to the S. Alouette River in spring. The present target is 50,000 smolts annually. The Institute also rears chum fry in ponds for release back to the river, the present target is 1.5 million releases per annum. There are plans for pink and chinook salmon enhancement along similar lines.

FLOW REGIME

The pre-impoundment annual mean discharge of the S. Alouette River was about 23 m^3/s while the post-impoundment mean flow in the early 1960's was 2.4 m^3/s (as measured at the 232nd Street WSC gauge). This dropped to 1.9 m^3/s following the 1971 agreement between DFO and B.C. Hydro to release 0.06 m^3/s constantly from the reservoir (Walker 1983). Impoundment has completely altered the flow regime of the S. Alouette River (Figures 7 and 8), but has not eliminated the occurrence of flash floods which are detrimental to rearing habitats and downstream spawning gravel beds (Hartman 1968, Slaney 1973), but which also benefit habitat quality by flushing out fine sediment deposits (B.C. Hydro, pers.com.) Timber removal has occurred throughout the watershed over large areas and together with the associated urbanization has increased the surface run-off to the river and increased the incidence of flooding (Walker 1983).

A great deal of attention has been paid to the minimum flows prevailing in the S. Alouette River since these are normally very low (Figures 7 and 8) and are considered to be critical in many reaches for rearing salmonids (B.C. Fish and Game Branch 1969). Based on the pre-impoundment annual minimum flows which ranged from 1.1 to about 4 m^3/s, a release from the dam of 2.3 m^3/s (80 cfs) has been a basis for recommendations for spawning periods. Stable maximum flows from April through September are highly desirable, as well as maximum specified rates of increase in releases. Sudden releases of very cold water are considered potentially deleterious to stream productivity (DFO 1983a).

A 1982 survey of the river (Andrew et al. 1982) indicated that discharges of 2.3 m^3/s from the reservoir would be required to obtain 100 percent coverage of wetted areas within pink salmon spawning habitats. A detailed survey of several sites in the river in 1984 (Sookachoff 1984) led to a revised recommendation of a 1.5 m^3/s (53 cfs) release from the reservoir during spawning and incubation (mid-October through April) and a release of 0.6 m^3/s (22 cfs) during rearing periods. These releases would permit 60 percent coverage of spawning areas and would provide for adequate flows for migration, spawning, incubation and rearing for coho, chum and pink salmon, as well as steelhead trout.

HABITATS

Below Impoundment

The length of the South Alouette River subject to the influence of the hydroelectric impoundment is 25 km, from the impounding dam to the confluence with the Pitt River. The river is supplied by numerous small tributaries, including the North Alouette River.

The upper 11 km is a steep gradient stream flowing through shallow wooded valleys, and consists mainly of rapids and pools interspersed with boulders, rocks and patches of gravels (Walker 1983). A 1.7 m^3/s flow would ensure the availability of about 10 percent of the wetted area (Andrew et al. 1982). The gradient of the next 2.5 km is considerably less, and consists of series of rapids, riffles and runs. The reach has excellent gravels with about 50 percent of the wetted area suitable for spawning. A flow of 2.3 m^3/s (80 cfs) would ensure 100 percent use of the wetted area by pink salmon (Andrew et al. 1982). The next 2 km consists of riffles and pools with sandy gravels (Walker 1983), but is heavily silted and has little potential for pink salmon spawning (Andrew et al. 1982). The lower 6 km reach has been channelled and diked, has a very low gradient with muddy substrates and is of little value as salmon habitat. Gravel removal in numerous reaches throughout the river commenced in 1954 and were stopped in the mid-70's. Declines in coho and chum salmon followed the gravel removal operations. Urbanization and waste disposal are additional factors causing habitat degradation (DFO, escapement files). Road maintenance in the difficult terrain along the South Alouette is responsible for considerable silt inflow (B.C. Hydro, pers. com.).

The present S. Alouette River flows in a channel which was developed under much larger flows. Consequently there are no side channels and very little bank overflow (Walker 1983). Changes in flows over a wide range consequently do not drastically affect the wetted width of many reaches.

The river is highly diverse in its characteristics (Walker 1983) and includes chutes, cascades, riffles and pools. Substrates range from gravels to rubble, boulders and sand. There is much variety in habitat conditions for rearing juvenile salmonids. The continual encroachment of deciduous and coniferous streambank vegetation into the streambed following the withholding of the larger annual floods has increased the incidence of bank shading and has improved rearing conditions.

Above Impoundment

Alouette Lake is a fairly oligotrophic lake with a severe drawdown (mean about 13.7 m) for its mean depth (64 m). The pH is slightly acidic (6.6), and total phosphates, total nitrogen and total dissolved solids are all low (EQUIS data, cited by B.C. Hydro n.d.). The lake has been restocked at various intervals by the provincial fisheries agency with lake trout, cutthroat trout and rainbow trout (Facchin 1979). Kokanee and Dolly Varden are also reported to occur in the lake (B.C. Hydro n.d.). The tributaries above the impounding dam are believed to have limited salmon habitat due to falls and gradients, and a fishway over the dam is not considered to be an economically feasible development (B.C. Ministry of Environment 1979). Access into the lake would lead to salmon being flushed through the power tunnel into the Stave lake system, with consequent problems with returning adult spawners.

SALMON POPULATIONS

Historic Populations

All five salmon species historically occurred in the Alouette River system (McMynn 1953). Large runs of sockeye, chinook, coho, chum, steelhead and cutthroat took place to Alouette Lake prior to 1926. Gold Creek was reported as being an important spawning stream. Chinook were not reported after construction of the Alouette Dam in 1926, and sockeye disappeared in 1930.

Escapements

Present coho escapements to the Alouette River (Figure 9) number in the hundreds. Coho had mean escapements of 450 from 1935 through 1955 and declined to 250 or less from 1956 through 61. The decline was not directly correlated with hydroelectric development and other factors were suspected to be responsible (Todd 1962). Chum salmon have increased in abundance due to enhancement, and now have runs of 8000 to 15000 each year. The 1982 chum escapement of 18,500 was the largest on record, while coho ran at 600 above average, this number including stock%d coho returns. Pink salmon appeared in moderate runs of up to 35,000 on an odd-yearly cycle until the mid-40's and then declined sharply during the 50's, possibly due to elimination of spawning habitats by gravel excavations in the river (Todd 1962).

Spawning and Rearing

Coho spawning is reported to occur over a 17 km reach as far up as the Alouette Dam, but the lower portions of this reach are likely only marginal habitat in view of urban encroachment and other impacts. Spawning takes place from late October to early January. Coho emergence extends from early April through May (Walker 1983) and the fry remain in the system for 13 months (Hartman 1968). Most coho fry rear in pools and riffles of the upper river. Coho smolt migration takes place in May.

Chum spawning occurs normally only in the lower river over a 4 km reach, but in years of high abundance, chum spawn as far upstream as the Correctional Institute, making use of an additional 5 km. Chum spawning takes place from October through December. Incubation takes place until mid-May. Chum fry migrate to the Fraser River and the estuary immediately after emergence.

PROJECT OPERATIONAL IMPACTS

Much of the habitat degradation in the Alouette River has followed hydroelectric development and is the consequence of accumulated impacts of urban, agricultural and industrial development into the active flood channel. The operation of the impoundment creates further negative impacts on remaining salmon habitat resources.

In-Migration of Spawners

Present regulated flows are too low for spawners to effectively ascend the upper reaches of the river in about 60 percent of the years in which post-impoundment flows have been gauged on the Alouette (Walker 1983). Flows of 5.7 m^3/s (200 cfs) are considered necessary for efficient spawning migrations, based on comparisons with other systems in B.C., e.g. the Big Qualicum River (Andrew et al. 1982) but are usually below this level from July through September. A water release of about 1.5 m^3/s (53 cfs) would be necessary to achieve this overall flow level in the middle sections of the river (Sookachoff 1984). To date, no agreement with B.C. Hydro has been reached on establishing larger releases from the reservoir.

Flushing of Habitats and Gravels

Impoundment has apparently reduced but not eliminated the occurrence of flooding in the South Alouette River system. The high precipitation in the region coupled with the relatively limited reservoir storage and precipitous nature of the upper watershed leads to a high incidence of seasonal flooding, which is aggravated by some management practices related to the hydroelectric installations, e.g. cleaning of the trash-racks (B.C. Hydro 1983).

Water Temperatures

Problems with lethal water temperatures (about 25° C and higher) are closely connected with low flows in summer (Hartman 1968). Temperatures as high as 27° C have been measured in the lower river system and are believed to have led to a decline in rainbow trout throughout the system.

SALMON MANAGEMENT REQUIREMENTS

Modification of the water release schedule from the Alouette Lake reservoir could potentially increase salmon productivity in the South Alouette River system. Although the river has been impacted by urban encroachment, channelization, sewage and waste inflows, and previous gravel extraction, the remaining habitats are judged to have potential for increases in spawning and rearing capacity if the water budget for the downstream salmon resources was improved (Walker 1983, Sookachoff 1984). Specifically this would entail the following.

a. releases through the dam should be increased to those recommended on the basis of river habitat surveys, i.e. 1.5 m^3/s (53 cfs) from October through April to facilitate spawning and incubation, and 0.6 m^3/s (22 cfs) from May to September to provide for adequate rearing conditions.

b. consideration should be given to modifying the reservoir rule curve to provide for improved storage in Alouette Lake and transfer to Stave Lake so as to minimize the probability of having to spill into the Alouette River.

Recent discharges to the S. Alouette River have been higher than the 0.06 m^3/s agreed upon in 1971 (Figure 10) but are still considerably lower than the recommended releases during the in-migration and spawning periods. However, releases in summer 1986 were in excess of those recommended, indicating that water is sometimes available for fishery purposes in the S. Alouette River. In recent years the dam operator has responded to specific requests from DFO and has increased releases to the river to alleviate high temperature problems in summer (B.C. Hydro, pers. com.).

B.C. Hydro has experienced difficulty in managing all the run-off in a system as erratic and unpredictable as the S. Alouette, while attempting to keep power flows as high as possible. Forecasting of lake inflows is subject to considerable error. The power tunnel trashracks require cleaning approximately every 10 years which requires a cessation in flow for several weeks (B.C. Hydro 1983). If large inflows occur during this period, the likelihood of a spill is considerably increased. The S. Alouette channel has decreased capacity due to bed rising and vegetation intrusion with a resultant loss in channel storage capacity. Reducing the probability of sudden discharges from the reservoir would require that the lake be drawn down to accommodate larger inflows and this in turn would require a change in the rule curve used to manage the reservoir. In general, effective management of the Alouette system requires a high degree of coordination between B.C. Hydro and fishery management agencies, as well as a sophisticated and responsive system of predicting and adjusting to changing inflows.

STAVE RIVER

PROJECT

Description

Two hydroelectric dams exist on the Stave River in the lower Fraser Valley, i.e. Stave Falls and Ruskin (Figure 11). The former is a concrete gravity dam of 26 m height and 67 m length, equipped with a 6 m gated outlet through the penstocks. There is no spillway on the structure. A separate saddle dam (Blind Slough Dam) of 18 m height and 195 m length is provided with sluiceways and four radial gates. The impounded lake has a surface area of 6200 ha and a total volume of 581 million m^3. Stave Falls was built in 1911 and the dam wall was raised in 1922-23. The generating plant has a nameplate capacity of 52.5 MW.

Ruskin Dam lies below Stave Falls and is a 59 m high, 125 long, concrete gravity dam equipped with a 3700 m^3/s capacity spillway and seven radial gates. The impoundment (Hayward Lake) is 300 ha in extent and is essentially a run-of-river reservoir for the flows routed from Stave Falls. Ruskin was completed in 1930 and the generating plant has a nameplate capacity of 105.6 MW.

Both Stave Falls and Ruskin generating stations make use of water diverted into Stave and Hayward lakes from Alouette Lake (see below).

Water Licences and Operational Constraints

A number of water licences have been issued for the Stave Falls and Ruskin projects over the years. The most recent, issued in 1961, entitles the holder to store 274 million m^3 of water and to use a maximum quantity of 178 m^3/s (6300 cfs). There are no provisions for releases for fisheries or any other purposes.

Electrical Generation

Stave Falls and Ruskin together contribute from 1 to 3 percent of B.C. Hydro's total monthly hydroelectrically derived power (maximum of about 63 million kWH per month) at 6 to 80 percent of their maximum capacity (B.C. Hydro, Operations Control Department statistics).

Stave and Ruskin once provided the bulk of power used in the B.C. lower mainland prior to the development of the Peace River. The Stave plant is now more than 75 years old and requires frequent maintenance. The 60 kV transmission line which supply links the Stave and Ruskin plants to B.C. Hydro's integrated grid system is not able to supply the required load at all times without peaking operations at the two plants.

Enhancement Facilities

No fish enhancement facilities were established in conjunction with the hydroelectric development. DFO established incubation boxes and rearing ponds in 1981. A hatchery on Inch Creek (near Nicomen Slough on the Fraser River) was completed in 1984 (MacKinlay 1985a) and utilizes Stave River as a satellite stream for chum salmon production. A side channel equipped with a rock berm to control inflows is located adjacent to the main channel and is used extensively by chum salmon; the date of construction has not been documented.

FLOW REGIME

There is no WSC gauging station below the Ruskin Dam. Discharges from the Ruskin power plant are highly variable on a daily basis (Figure 12) and completely dominate the flow regime within the short reach of the river below the dam.

HABITATS

Below Impoundments

The Stave River from the Ruskin Dam impoundment to the Fraser River confluence is a 3.5 km reach subject to tidal influence. Shorelines are mainly sands and fine gravels and are subject to fluctuating water levels due to tides and the changing discharges through the Ruskin plant turbines (Brown and Musgrave 1979). In the 1970's the area of good quality spawning gravels was estimated at about 65,000 m^2, with another 25,000 m^2 available but subject to exposure due to fluctuations in powerplant discharges (Palmer 1972). Urban and industrial encroachment has impacted on numerous areas along the shorelines. An excavated side channel provides additional spawning habitat for chum salmon.

Above Impoundments

Water quality data (EQUIS data cited by B.C. Hydro n.d.) indicate that Stave Lake is a moderately oligotrophic reservoir, with a pH of 6.6, low phosphate and nitrogen content, and generally low total dissolved solids content. The water is usually clear, except in the upper areas following heavy precipitation events. Stave Lake has a recreational fishery for rainbow, cutthroat trout and Dolly Varden (B.C. Fishery Branch, pers. com.) but is unused by anadromous salmon. Hayward Lake has not been studied in detail, but has a very high flushing rate, and is therefore probably biologically unproductive. Fish ladders into Stave and Hayward lakes have not been seriously considered, probably due to the lack of abundant habitats above the dams.

SALMON POPULATIONS

Historic Populations

All five Pacific salmon species plus anadromous steelhead and possibly sea-run cutthroat trout historically used the Stave River and lake system (Brown and Musgrave 1979). Ruskin Dam is impassable to anadromous salmonids.

Escapements

Coho escapements to the relatively short reach of the Stave River below Ruskin Dam have fluctuated considerably over the periods of record (Figure 13) and generally number from 600 to 800. Chinook were never abundant in the period of record and presently appear in very small numbers. Pink salmon have not been recorded since 1977; prior to that date they appeared in odd-yearly cycles. Chum salmon is the dominant stock in the system and runs numbered in the low thousands from the commencement of escapement counts until about 1965 when runs increased to between 30,000 and 70,000; the reasons for the sharp increases are not documented. Following a sharp decline in numbers in the mid-1970's (Figure 13), runs have been increased since 1981 by enhancement of the Stave stocks from the Inch Creek hatchery.

Spawning and Rearing

The best spawning areas for chum salmon are reported as occurring along the main channel and some side channels within about 1 km below Ruskin Dam (Palmer 1972). Chum salmon also make use of an excavated side channel. The locations of rearing habitat for species such as coho which remain within the river for up to a year following emergence have not been investigated. Salmon fry are frequently seen stranded along sand bars in the lower Stave River when water levels subside rapidly following turbine shutdown at the Ruskin power plant (Fishery Officer reports). Pink and chum salmon fry are presumed to move directly into the Fraser River following emergence, but the timing and patterns of coho and chinook out-migrations are unknown.

PROJECT OPERATIONAL IMPACTS

Stranding of fry following rapid changes in discharges through the Ruskin Dam turbines is probably the main operational impact (Palmer 1972, Brown and Musgrave 1979). The extent of fry mortality or the impact on salmon stocks using the lower Stave River has not been investigated. Both Ruskin and Stave lake are peaking plants for the Fraser Valley area and the regular mode of operation for many years has apparently included shutdown at night and over weekends, with resultant sharp fluctuations in discharges and probably severe impacts on incubating eggs and rearing fry. In early 1988 failure of the trashracks above Ruskin Dam necessitated a shutdown of most turbines, leading to very low flows and exposure of incubating chum salmon eggs in the spawning channel in the lower Stave River (DFO, B.C. Hydro, pers. com.). A series of experimental releases was studied in 1989 and led to agreement between B.C. Hydro and DFO on the need for block loading flows of 84 m^3/s (3000 cfs) and 28 m^3/s (1000 cfs) during chum spawning and incubation periods respectively. In 1990 DFO contoured the 360 m long main chum spawning bed below the dam to make it more functional during the block flows provided (DFO, pers. com.).

SALMON MANAGEMENT REQUIREMENTS

Little attention has been paid to the Stave River habitats because of the relatively limited resource values in comparison to the overall Fraser River system. However, the Stave River is a satellite of the Inch Creek hatchery for chum salmon enhancement, and hence any improvements to the overall flow regime would greatly improve the cost-efficiency of salmonid enhancement in the system. Reduction in diurnal release variations and establishment of an acceptable mean discharge during spawning periods are currently being studied as means of increasing over-winter egg survival. The relatively short length of river below the hydroelectric dams and the total dominance of the system by the hydroelectric discharges makes effective flow management throughout the year a more difficult under-taking.

WAHLEACH (JONES) CREEK

PROJECT

Description

The project consists of an 18 m high, 418 m long, earthfill dam constructed across the outlet of Wahleach (Jones) Lake in the upper Fraser Valley (Figure 14). A 3 m high dam across nearby Boulder Creek diverts water into Wahleach Lake. Wahleach Dam has a 122 m^3/s capacity spillway and the Boulder Creek diversion dam is equipped with an 0.6 m diameter fish water sluice with a manual sliding gate. A 4.5 km conduit leads water from Wahleach Lake to a powerhouse on the left bank of the Fraser River, located above Cheam View. The power plant has a nameplate generating capacity of 60 MW. The development was completed in 1952.

Water Licences and Operational Constraints

The water licence permits the storage of 180 million m^3 of water per year and the maximum diversion of 13 m^3/s (470 cfs) for power purposes. No stipulations exist for the release of water for other purposes. The releases to the spawning channel (see below) are based on an agreement between DFO and B.C. Hydro (Fraser and Fedorenko 1983).

Electrical Generation

Between January 1984 and June 1987 the Wahleach power plant generated from zero to 51 million kWH per month (114 percent of nameplate capacity). Generation varied considerably from month to month, with no fixed pattern of generation at any time of the year. For 3 out of the 42 months in the period of record there was no power generated, and for about half of the period the plant's generation was less than a third of capacity.

Enhancement Facilities

The Jones Creek spawning channel was constructed and brought into operation in 1954 to maintain the existing pink salmon runs in Wahleach (Jones) Creek following reduction in creek flows by impoundment and diversion. The channel was designed by DFO and paid for by the B.C. Electric Company (Hourston and MacKinnon 1956), and was intended to replace the natural pink salmon spawning area in the creek, estimated at 1800 m^2 and able to support 6300 spawning pink salmon. The channel is 600 m long, 5 to 6.5 m wide, and provides for a mean water depth of 30 to 60 cm and a velocity of 0.3 to 0.7 m/s through the use of baffles. A 70 m long diversion structure at the lower end prevents pink and other salmon from entering the creek channel (MacKinnon et al. 1961). The mean flow required for channel operation is 0.8 m^3/s (29 cfs) during spawning (15 September to 31 October), 0.4 m^3/s (14 cfs) during incubation (31 October to 31 March), and 0.6 m^3/s (21 cfs) during fry out-migrations (10 April to 23 May) (DFO 1987). Bi-annual maintenance of the channel is funded by B.C. Hydro.

FLOW REGIME

There are no detailed stream gauging data for Wahleach Creek. The channel operates independently of the hydroelectric development for much of the time, but requests are sometimes made to B.C. Hydro to release up to 1.4 m^3/s between 15 September and the end of October to provide sufficient water for in-migrating pink salmon.

HABITATS

Below Impoundment

Salmon use of much of the natural creek below the impoundment was precluded by the presence of a diversion structure at the entrance to the spawning channel. Pink, chum and a few coho have continued to use naturally available habitats in the lower portion of the creek bed, but no data are available on the extent of quality of these habitats.

Above Impoundment

Wahleach Lake is about 340 ha in extent with a total volume of some 700 million m^3 and an average drawdown of about 20 m. No limnological data are available. The dam is not equipped with a fishway. Kokanee were stocked into the lake on an annual basis in the 30's (Facchin 1979) and still persist along with cutthroat trout, but no population data are available.

SALMON POPULATIONS

Historic Populations

Historically Wahleach Creek supported all five species of Pacific salmon (Fraser and Fedorenko 1983). Pink salmon were the major users of Wahleach Creek prior to the hydroelectric development and runs numbered between 7000 and 10,000 on odd-yearly cycles. Chum and coho numbering in the hundreds also made use of the natural creek (MacKinnon et al. 1961). A few chinook and up to 700 sockeye were observed annually until about 1941; the reason for their disappearance is not documented.

Escapements

Pink salmon escapements to Wahleach Creek prior to the impoundment numbered up to approximately 7000 on an odd-yearly cycle (Figure 15). Reduced flows in 1953 during filling of the newly impounded lake caused severe depletion of the stocks, and only 400 were enumerated in the new spawning channel in 1955. Numbers have since fluctuated between about 2000 and 4000 with the channel being used by 50 to 80 percent of spawning escapements (Figure 15). Silting of the gravel beds in the spawning channel (resulting from run-off from logging operations) has been a major cause of declining stock size in the Wahleach pink salmon population (Fraser and Fedorenko 1983). Egg to fry survival during the initial years of operation of the spawning channel averaged about 30 percent (MacKinnon et al. 1961) but rises to 65 to 80 percent following years when gravels have been replaced (Fraser and Fedorenko 1983). Coho and chum salmon use the spawning channel in small numbers (Figure 15).

Spawning and Rearing

Spawning grounds in Wahleach Creek are confined by cascades and the spawning channel diversion to the lower 0.8 km of the natural creek. Chum salmon are usually the first arrivals in late August to early September, with peak spawning taking place by late September (Fraser and Fedorenko 1983). Pink salmon arrive in mid-September and peak spawning takes place in mid-October. The few coho using the system arrive by early November and spawn from mid-November through to late December. Small numbers of pink, coho and chum salmon use Lorenzetti Creek, a lower tributary to Wahleach Creek (Marshall et al. 1980).

PROJECT OPERATIONAL IMPACTS

Based on the escapement records (Figure 15) the Wahleach development was responsible for a reduction in pink salmon runs, which were not fully rehabilitated to former levels by the installation of the spawning channel. Major changes in the design of the spawning channel have been recommended (Fraser and Fedorenko 1983), including a new settling basin, a sluiceway, use of mechanical gravel cleaners and stabilization of channel banks with rip-rap. Continuing impacts to the fisheries resource by logging and road maintenance operations in the watershed are largely independent of the operation of the hydroelectric facilities.

SALMON MANAGEMENT REQUIREMENTS

Fraser and Fedorenko (1983) have identified the major problems of the Wahleach Creek spawning channel as being siltation and various issues related to the outmoded design. Control of siltation is related closely to the need to control logging and related activities within the local watershed and an improved channel design to reduce or eliminate silt build-up.

BRIDGE RIVER

PROJECT

Description

The Bridge River is controlled by two hydroelectric impoundments (Figure 16). The La Joie Dam is an 87 m high, 1000 m long, earthfill dam located at La Joie Falls above the Hurley River confluence, and about 90 km above the Bridge River confluence with the Fraser River. The impoundment, Downton Lake, has a surface area of 2400 ha and a volume of some 720 million m^3. The dam has an ungated spillway and two separate low level outlets equipped with Howell-Bunger valves. A generating plant below the dam has a nameplate capacity of 22 MW. The project was constructed in 1948, and redeveloped in 1957.

About 60 km further downstream and 30 km above the Bridge River - Fraser River confluence is located the Terzaghi Dam, a 54 m high, 360 m long, earthfill dam with a gated concrete spillway and a small low--level outlet. The impoundment, Carpenter Lake, has a surface area of approximate 4900 ha and a volume of 1125 million m^3. There is no powerhouse at the dam site. Two separate 5 km tunnels lead water from Carpenter Lake into Seton lake through powerhouses which together have a capacity of 428 MW. From Seton Lake the diverted water continues through the Seton Creek generating station. Terzaghi Dam was built in 1948 and raised in 1960 following reconstruction of the La Joie Dam.

Below Terzaghi Dam the Bridge River flows for about 10 km, fed only by small tributary streams until it is joined by the Yalakom River, and then continues for another 20 km to join the Fraser River above Lillooet.

Water Licences and Operational Constraints

The water licences for the Bridge River projects permit a total diversion of 150 m^3/s (5400 cfs). There are no provisions for release of water for fisheries or other purposes. Requests from DFO and the provincial Fisheries Branch for water releases through Terzaghi Dam over the years have been rejected by B.C. Hydro because of the perceived high costs of the foregone power generation and the lack of a suitable outlet for continuous flow releases in Terzaghi Dam (B.C. Hydro 1982). A test release was carried pout in 1988 (see below).

Electrical Generation

The Bridge River plants (Bridge 1 and 2) normally operate at 60 to 80 percent of their capacity from September through April, during which time they generate up to 260 million kWH per month. From May through August generation is cut back to much lower outputs. Monthly contributions to the B.C. Hydro hydroelectric grid range from 4 to 10 percent. The smaller La Joie plant contributes from 10 to 15 million kWH monthly, about 0.3 to 0.5 percent of the total hydroelectric grid, and operates at a high capacity of 80 to 90 percent in most months.

Enhancement Facilities

No fisheries mitigation or compensation measures were undertaken by the utility for the Bridge River developments. DFO attempted to save the chinook stock in Tyaughton Creek by planting green eggs to Portage and Gates creeks with unknown results (DFO 1983b). Several community-based enhancement projects (incubation boxes) are based in Lytton, and the

Salmonid Enhancement Program has examined the possibilities of enhancement in the system on several occasions (DFO 1983b).

FLOW REGIME

The WSC gauge at the Terzaghi Dam site was dismantled following completion of the dam in 1948, and only pre-impoundment flows are available (Figures 17 and 18). These indicate that the Bridge River had a very wide range in seasonal flows with a mean annual maximum discharge from 250 to 350 m^3/s and a mean annual minimum about 15 m^3/s. The year to year mean discharge was fairly constant around 100 m^3/s, indicative of the wide elevational ranges within the Bridge River watershed (from glaciers to relatively low relief interior plains). Flows from July through October generally approximated the mean annual discharges of about 100 m^3/s, and minimum monthly discharges in this period were in the 30 to 150 m^3/s range. Mean minimum monthly winter flows in the lower reaches were of the order of 10 to 15 m^3/s.

La Joie and Terzaghi dams effectively retain inflows in most years, but spills from Terzaghi Dam to the lower Bridge River occur for short durations in years of very high run-off; this has occurred in only 6 of the past 22 years (B.C. Hydro, Operations Control Department statistics).

A test release of 0.5 m^3/s through a small diameter low-level valve was attempted in 1988 with minimal benefits to instream flows since most of the discharge drained into the substrate (B.C. Hydro, pers. com.).

HABITATS

Below Impoundment

Some sections of the lower Bridge River have been surveyed for habitat types and flow conditions (Hebden 1981), and cross sectional and air photo analysis was carried out in 1988 during a test release of approximately 0.5 m^3/s (B.C. Hydro, pers. com.). Significant characteristics in terms of salmon utilization are the rapids in the river about 1 km and 4.5 km up from the mouth, which are reported to restrict in-migrating salmon at certain flows, and numerous debris blocks which may retard salmon migrations, e.g. 1 km below the Yalakom-Bridge confluence (DFO 1983b). Both the Bridge and Yalakom rivers carry high silt loads derived from slides, outwashes, run-off from deforested areas, highway construction, placer mining operations and some glacial flour from higher elevations.

Large areas within the channels of the Bridge and Yalakom rivers have been, and continue to be, impacted by placer mining (gold) operations dating from the previous century (DFO 1962a). These operations continue in many areas, sometimes accompanied by extensive dredging of channel substrates.

Above Impoundment

There are no detailed limnological data on Carpenter or Downton lakes. Salmon are presently excluded from the entire upper reach of the Bridge River (about 80 km), plus extensive reaches of Tyaughton Creek which were once productive spawning and rearing habitats.

SALMON POPULATIONS

Historic Populations

Prior to impoundment, chinook spawned in the lower reaches of Tyaughton Creek (now a tributary steam to Carpenter lake), and in Ferguson Creek (DFO 1983b). Chinook were salvaged from Tyaughton Creek following impoundment and eggs planted to the Yalakom and Bridge rivers and to Gates and Portage creeks on Seton lake from 1951 to 1953 with little success. Ferguson Creek habitats were subsequently destroyed by placer mining. Chinook ascended the Yalakom River, but a canyon about 18 km above the Bridge-Yalakom confluence may have been an impedance. La Joie Falls were probably impassable to salmon before dam construction. Up to 100 chinook spawned in the lower Yalakom in 1958, and chinook were observed at the mouth of the Bridge River. Sockeye, coho and chum occurred in the Bridge and Hurley rivers in the 20's (DFO 1983b), but no data on abundance are available. In 1957 a blockage of the Fraser River at the Bridge River rapids (on the Fraser River upstream of the Bridge-Fraser confluence) caused some sockeye to ascend the Bridge and Yalakom rivers, and spawning activity was observed.

Pink salmon were not reported in earlier accounts of the Bridge River system, although they may have been present. Pink migrations up the Fraser were stopped by the Hells gate slide, and they were reported in the Bridge River for the first time in 1959, following the Hell's Gate fishway expansion in 1956.

Escapements

Pink salmon dominate the escapements to the Bridge River at the present time (Figure 19) and have been increasing since the Hell's Gate fishway was improved in 1956. In 1957 they were observed at the mouth of the Bridge River and in 1959 some 2000 were counted spawning in the mainstem. Numbers peaked in 1979, after which the 2-yearly cycles were relatively constant at about 30,000. Some pink salmon ascend the Yalakom River to spawn. Pink salmon escapements in the Bridge River may now be increasing because of the success of the pink salmon spawning channels at Seton Creek. Pink salmon migrations take place from mid-September to late October.

Present chinook escapements are small, about 100, and have reached a maximum of about 500. Chinook runs occur in mid-August. Coho move into the system in early October, and runs fluctuate up to 1000, but are often very small. Present sockeye escapements to the Bridge River system are very small and erratic. The present steelhead escapement is estimated at about 500 (B.W. Hebden, MOE, pers. com.).

Spawning and Rearing

Pink spawning in the lower Bridge River is recorded as occurring over the entire length from the Fraser River confluence to below the Terzaghi Dam where only bed seepage flows are available (DFO 1983b). The highest spawning densities are recorded for the reach below Camoo Creek, but apparently are sometimes restricted to a 3 km reach above the mouth when upward access is restricted by the rapids. Pink spawning takes place from 15 September until the end of October, with a peak around 10 October.

Chinook spawning takes place from late August to mid-September. Coho are reported to spawn from late October to early November, while sockeye spawning occurs from mid-August to mid-September. Pink salmon fry emergence takes place from March through May, and direct migration out to the Fraser River is assumed to occur. Peak pink fry migration occurs in the last 2 weeks in April. No information is available on rearing or out-migrations of coho, chinook or sockeye.

PROJECT OPERATIONAL IMPACTS

Impoundment of the Bridge River and diversion of all but flood peak discharges to Seton Lake has severely altered the salmon production system below Terzaghi Dam. Specific quantitative data are not available on the negative impacts on the salmon resource, but the following are likely.

Delays and/or Blockages in Upstream Migrations

Several major falls in the lower Bridge River can impede upstream migration of adult salmon, especially pink salmon which move up the system in October when Yalakom River flows are very low. This is probably a very common occurrence in the lower Bridge River. Although there is a low-level release valve in Terzaghi Dam, this does not appear to have been designed for long-term operations. Use of the valve for downstream releases was tested in 1988 with unsatisfactory results (see above).

Reductions in Mainstem Spawning and Incubation Areas

The entire reach of the lower Bridge River is regarded as potential pink spawning habitat, but the wetted area is likely highly restricted in October when peak spawning takes place. In 1964 up to 1000 sockeye and some chinook spawned below the Terzaghi Dam in areas which rapidly dried up during incubation (DFO 1983b).

Attraction of Adults to Bridge River Tailraces

Chinook were seen at the Bridge River plant tailraces on Seton Lake from 1949 to 1953 (DFO 1983b), presumably attracted by Bridge River water. This may be a continuing problem, especially for pink salmon from the lower Bridge River which subsequently home to Seton Lake which contains a mixture of Bridge River water. No information on the current extent of such homing is available.

SALMON MANAGEMENT REQUIREMENTS

There is a need to determine what the optimum flow regime in the lower Bridge River should be for migration, spawning, incubation and rearing of salmon, especially pink salmon. Because of the size of the river channel and the pervious substrates, these flows would probably have to be substantial. Based on this and a realistic cost for water from Carpenter Lake, a release schedule should be developed for Terzaghi Dam. The lack of continuous release facilities in the Terzaghi Dam is a major obstacle to improved water management for salmon, and the costs of such a device should be computed and compared to the values of the enhanced salmon resources if water were made available.

As with many salmon-producing rivers in B.C., the Bridge River is subject to several impacts which are interrelated in their effects on salmon resources. Improvement of the downstream flow regime should be considered only in relation to control and management of other significant factors such as mining, deforestation and road construction. An integrated watershed management plan for the system is a priority requirement for further salmonid management.

SETON CREEK

PROJECT

Description

The Seton Creek project consists of a 7.6 m high, 130 m long, concrete gravity dam located 0.6 km below the outlet of Seton Lake and approximately 4 km above the confluence of Seton Creek and the Fraser River (Figure 20). The present dam is provided with a radial gate spillway, a siphon spillway, a power canal inlet, a fish water sluice of 12.5 m^3/s flow capacity, and a fishway. The latter is 2.5 m wide with vertical baffles and an estimated capacity of about 1 m^3/s. The total capacity of the siphons plus the overflow sections is about 350 m^3/s. Cayoosh Creek flows into Seton Creek about 1.4 km below Seton Dam and is itself impounded by a temporary rockfill timber crib dam 5.8 m high and 250 m long. A 450 m concrete-lined diversion tunnel links the forebay of Cayoosh Creek dam to Seton Lake (Figure 20).

A 4 km long concrete-lined power canal leads flows over Cayoosh Creek to a generating station, located on the right bank of the Fraser River about 1 km downstream from the Seton Creek - Fraser River confluence (Figure 20). The power house tailrace, a source of major problems for migrating salmon (see below), is 50 m wide, 75 m long, and accommodates fluctuations in water levels up to 7 m The generating station has a single turbine with a nameplate capacity of 42 MW. About 80 percent of the total discharges through the powerhouse originate from the Bridge River system via diversions into Seton Lake, the remainder being derived from local run-off into Seton Lake. The project was commenced in late 1953 and was in service by 1956.

Water Licences and Operational Constraints

The conditional water licence, dated November 1953, authorized the B.C. Electric Company to divert a maximum of 3.2 x 10^9 m^3 per annum. Conflicts between the development and the salmon resources of the Seton - Anderson Lake system were recognized during project development, and both DFO and IPSFC had input to the design concept (DFO 1953a). As a result of this the conditional water licence contains clauses stipulating that the spill discharge at Seton Dam shall be maintained at 11.3 m^3/s (400 cfs) during adult sockeye migrations and at 5.7 m^3/s (200 cfs) at other times (or lesser amounts if so determined by the Minister of Fisheries).

The company accepted the fact that problems might occur at the tailrace but these could not be accurately forecast at the time and the company agreed to investigate and seek solutions (B.C. Electric Co. 1953). They also agreed to take necessary action to deal with any problems related to the passage of downstream migrants. The company further agreed to limit use of the radial gates for flow releases to emergency use and passage of flood flows only.

Electrical Generation

The Seton development was designed on the basis of minimum calculated flows from Seton and Cayoosh creeks, plus whatever is passed through the diversion tunnels from Bridge River via Carpenter Lake. The plant is operated at full load at all times, except for occasional maintenance periods (Operations Control Department, B.C. Hydro, pers. com.). Monthly contribution of Seton generation to the B.C. electrical grid from 1984 through 1987 varied from 0.1 to 1.2 percent.

Operation of the powerhouse in recent years has been modified in an attempt to meet the flow requirements of migrating sockeye salmon (see below). To reduce the likelihood of salmon congregating at the tailrace and gaining entry to the draft tubes, the plant has been run at full load or else shut down completely during salmon migration periods (July to November, depending on the run).

Enhancement Facilities

About 25,000 m^2 of pink salmon spawning area between Seton Lake and the dam were destroyed during and after construction in 1953-55 (IPSFC 1959). The total spawning capacity of the natural gravel beds was reduced to 60,000 spawners at most. As a result of this, the IPSFC constructed a 5000 m^2 (upper) spawning channel which was used for the first time in 1961, and which has since supported pink salmon spawning runs of 2500- 14,000 on an odd-yearly cycle. A second 17,500 m^2 channel with a capacity of about

20,000 spawners was added in time for use by the 1967 pink salmon run and has since been used to full capacity on an odd-yearly cycle.

FLOW REGIME

Post-impoundment flows monitored in Seton Creek (Inland Water Directorate 1988) are made up of water released through the fishway, the fish water sluice and through the spillway. Pre- impoundment flow data for Seton Creek were of very short duration, and do not permit any extensive comparisons of pre-and post--impoundment flow conditions. Superficial comparisons (Figures 21 and 22) indicate that the long-term mean annual regulated flow may be similar to that which existed under pre-impoundment conditions, but year-to-year variability has increased. Peak flows have increased, possibly by as much as 40 percent, due to sudden discharges over the spillways and through the radial gates (Figure 23). A maximum of about 110 m^3/s (4000 cfs) can be diverted down the power canal, and the live storage within Seton lake is limited. Mean minimum monthly flows appear relatively unchanged due to the minimum flow restrictions contained in the water licences and required in annual operating constraints recommended by DFO.

Frequent and ongoing negotiations between B.C. Hydro, IPSFC and DFO over the years have resulted in a set of operating recommendations for the plant in order to safeguard spawning and incubating pink salmon in Seton Creek, to permit efficient passage of adult sockeye into Seton Lake, and to facilitate passage of out-migrating sockeye smolts. Minimum permissible discharges over the spillway now vary from 5.7 to 11.3 m^3/s, depending on the presence of migrating salmon in the system, and maximum allowable discharges during spawning migrations are now limited to about 55 m^3/s (2000 cfs), except in emergencies. Constraints on minimum and maximum discharges were initially set on the basis of an approximation to natural flows, and have been fine-tuned over the years, based on observations of successful fish passage and spawning.

Required flows for salmon have generally been met by B.C. Hydro, but limits to their ability to control flows have occasionally occurred, e.g. in 1977 there was a need to suddenly increase spills at Seton because of storage problems in Carpenter and Downton Lakes (B.C. Hydro, Operations Division, pers. com.).

Flows in Cayoosh Creek typically range from 9 (November) to 50 m^3/s (July) during sockeye migrations and are significantly higher in conductivity, turbidity, alkalinity, hardness, calcium, sulphate and fluoride than Seton Lake water (Fretwell 1980). Cayoosh Creek inflows dilute Seton discharges and make them less attractive to migrating sockeye than the tailrace discharges which draw on pure Seton lake water and which are encountered first by Gates- and Portage creeks salmon moving up the Fraser River. This was identified as a major cause for sockeye delays at the tailrace in the years following project completion (IPSFC 1976). In 1979 a temporary gravel and cobble diversion tunnel was built across Cayoosh Creek and all flows greater than 7 m^3/s were diverted into Seton Lake via the reopened diversion tunnel (Fretwell 1980). This procedure has been repeated on an experimental basis until the present and has become an important management strategy to avert sockeye delays at the powerhouse tailrace (see below). Cayoosh Creek is much colder than Seton Creek (Fretwell 1980) and temperatures of the Seton creek outflow depend on the relative mix of the two sources.

HABITATS

Below Impoundment

The major habitat component affected by the Seton Creek hydroelectric development is the spawning beds within the 4 km reach between the existing dam and the creek mouth, which are used on a 2-year cycle by pink salmon. Small numbers of sockeye, coho and chinook have been reported as entering or using the Seton Creek spawning beds (DFO escapement records) but this use has usually been associated with delays in upstream migration related to flows and the majority of salmon usually move through the fishway into Seton lake (if the flow regime is appropriate) and on to Portage and Gates creeks.

Protection of pink salmon spawners and incubating eggs in Seton Creek has been a major objective of operational constraints on releases through the Seton Dam (in addition to providing sufficient water for sockeye migrations). At the present time (1988) DFO requires B.C. Hydro to limit spills to less than 56.6 m^3/s (2000 cfs) between 15 September and 31 May, and any spills during pink salmon incubation periods have to be not less than 50 percent of spills during pink salmon spawning periods (DFO 1987b).

Above Impoundment

The upstream limnological impacts of the Seton development have been assessed by comparison of Seton Lake with Anderson Lake (Geen and Andrew

1961). Temperature and total dissolved solids decreased following diversion of Bridge River water into Seton Lake, while turbidity increased. A dramatic reduction in zooplankton standing crops was attributed to a high flushing rate from the lake (Geen and Andrew 1961) but may also indicate a high cropping rate by sockeye smolts which have a high productivity in Seton lake (M. Fretwell, DFO, pers. com.). A positive impact of damming Seton lake has been the colder water temperatures passing to the pink spawning areas in Seton Creek (Geen and Andrew 1961).

SALMON POPULATIONS

Historic Populations

Records of early salmon migrations through the project area date back to 1901 when 150,000 to 200,000 sockeye were noted to move up Seton Creek from late July to early August and then move on to spawning areas in Gates Creek at the head of Anderson lake (DFO 1953b). About 7000 sockeye moved to Gates Creek in 1952 and were noted to also spawn at the upper end of Anderson lake. Spawning channels for sockeye were put into operation at Gates Creek in 1967-68.

Pink salmon runs to Seton Creek were monitored by the Seton Hatchery in 1905, 1907, 1909 and 1911, and were estimated at about 200,000. It is now considered that this number was far too many for the available spawning area in Seton Creek which at that time was approximately 5 km long, and these early data have to be treated with caution. In 1913 the Hell's Gate slide in the Fraser River stopped all pink salmon migrations until fishways led to the resumption of runs in 1947. From 1000 to 2000 pinks spawned below the Cayoosh Creek - Seton confluence in 1947 and 1949, and from 10,000 to 20,000 in 1951 (DFO 1953b). They were not reported as having entered Seton Lake. The 1955 escapement was 75,000 to 100,000, of which about 9000 went through the newly established fishway into the lake. The 1957 escapement was estimated at 59,000.

Small to moderate runs of up to 2000 chinook were reported through Seton Creek in earlier years (DFO 1953b). About 1000 were reported in 1943 in Seton Creek below the lake. The 1948 runs were very small (50 to 100) and the Bridge River discharges into Seton Lake were described as affecting the depth of water on the spawning grounds. Some earlier reports mention small runs of chinook to both Gates and Portage creeks, while others indicate that chinook did not use Gates Creek.

Coho were usually reported in Seton and Cayoosh creeks in earlier years, but only numbered some 2500 fish as this appeared to be the northern limit of their distribution within the Fraser River watershed.

Escapements

Unlike several other systems dealt with in this report, escapements to Seton Creek, Portage Creek, Gates Creek and the various associated spawning channels were estimated with a high degree of accuracy (Figure 24). Heavy mortalities to the 1973 sockeye runs to Gates and Portage creeks occurred at the Seton tailrace (IPSFC 1976) and showed up in low escapement counts at the spawning grounds (Figure 24). The low escapement to Portage Creek in 1985 might have been related to impacts suffered at Seton. At the present time it is not possible to correlate any of the fluctuations in escapement counts with specific key events at the Seton creek project, e.g. tailrace delays or powerhouse mortalities.

Spawning and Rearing

The spawning and rearing areas which are subject to the influence of the hydroelectric installation are those within Seton Creek below the dam, used mainly by large runs of 2- yearly cycle pink salmon, and small numbers of coho and chinook. Numbers of pink salmon using the creek have returned to high levels, following the completion of fish ladders at Hells Gate in the Fraser River. Specified maximum and minimum water releases over the spillway and through the radial gate at Seton dam (see below) appear to presently provide no significant constraints to pink salmon spawning, incubation and rearing in Seton Creek. Numbers of pink spawners and rearing fry are considerably in excess of the present carrying capacity of the spawning channels.

Sockeye smolts derived from Gates and Portage creeks migrate out of Seton lake through the powerhouse or over the spillway from March through June. The diel period of sockeye smolt migration is typically 2000 to 0400 hr., which is an important parameter in determining the extent of smolt mortality in the powerhouse turbines (see below). Pink fry originating from Seton Creek and the Seton spawning channels move back to the Fraser via Seton Creek and so avoid any contact with the powerhouse. Pink fry from Gates and Portage creeks and the shorelines of Seton Lake pass through the powerhouse where they are subjected to mortality (see below).

PROJECT OPERATIONAL IMPACTS

Delays at Tailrace

The large runs of sockeye through Seton Dam to Gates and Portage creeks have been the subject of considerable study (e.g. Andrew and Geen 1958, IPSFC 1976, Fretwell 1979, 1980, 1981a, 1981b, 1989). Returning spawners first encounter Seton water in the powerhouse tailrace and tend to congregate there. Seton Creek discharges into the Fraser River are normally diluted with Cayoosh Creek flows and so are less attractive to homing sockeye than the tailrace discharges. The first evidence of serious problems caused by this attraction to the tailrace was noted in 1973 when the Gates Creek run was significantly reduced, and a high incidence of head injuries was observed in sockeye spawners (IPSFC 1976).

Studies using radio-telemetered fish (Fretwell 1979, 1980, 1981a, 1981b) indicated that the Gates Creek sockeye run was delayed for an average of 93 hours when Cayoosh Creek inflows made up to 50 percent of Seton Creek discharges into the Fraser River. Sockeye are sensitive to proportions of Cayoosh Creek water of about 20 percent (Fretwell 1989). The Portage Creek run was delayed for an average of 29 hours at a time when Cayoosh flows were reduced to less than 13 percent of total Seton Creek discharges. The Portage Creek salmon were found to be more variable in their homing response but were sensitive to proportions of Cayoosh Creek water as low as 10 percent (Fretwell 1989). The length of the delay was considered to be a function of several variables, including the stage of the run, water temperatures, and any previous delays of fish during their Fraser River migration. In 1979 43 percent of Gates Creek sockeye in the tailrace failed to migrate due to extensive delays (Fretwell 1980). Many fish which left the tailrace and reached the mouth of Seton Creek turned back to the tailrace because of the stronger attraction of the pure Seton water at the latter. Those that entered Seton Creek were also found to be liable to turn back if spill discharges at Seton Dam were only about 11 m^3/s (400 cfs) but they continued their ascent at discharges of 30 to 50 m^3/s (1000 to 1800 cfs).

Fish milling in the tailrace are prevented from entering the turbine draft tube by full load discharges (about 115 m^3/s at 44 MW), but may do so at partial loads (< 20 MW) and get injured by the turbine runner (Fretwell 1980).

Pink salmon occasionally congregate at the tailrace but the problem is not as serious as with sockeye; pink salmon appear to have no discernible preference for Seton or Cayoosh Creek water Fretwell 1989).

Delays at Seton Dam and Spawning Channel

Discharges through the radial gate greater than about 60 m^3/s were found to cause delays of sockeye below the dam (Andrew and Geen 1958). Delays or injury have not been reported for discharges of 20 to 30 m^3/s (Fretwell 1980). Migrating sockeye have been observed to linger at the entrance to the lower pink salmon spawning channel (supplied by pure Seton lake water); this has not been reported in recent years when Cayoosh Creek water has been diverted into Seton Lake (Fretwell 1980).

Impingement on Screens and Trashracks

Pink salmon are frequently reported to ascend the fishway into the lake and then attempt to return downstream to the main pink spawning areas. In so doing they become impinged on the fish screens at the power canal intakes. Entrance of pink salmon into the power canal during plant shutdowns and cleaning of the fish screens has been reported (Fretwell 1980). Impingement of sockeye smolts on accumulated debris on the powerhouse trashracks has often been reported (B.C. Hydro, pers. com.) and similar impingement of pink fry may be a significant recurring problem.

Passage through Powerhouse

When the plant is in operation, most sockeye smolts appear to move through the powerhouse, where immediate mortality of at least 10 percent occurs but is very difficult to quantify accurately (Fretwell and Hamilton 1983). Scale loss has been observed to occur in smolts and this could affect ocean survival (DFO, pers. com.) When the plant is not in operation, smolts move over the Seton Dam spillway where mortality is negligible. If a plant shutdown occurs during the diel period of migration (2000 to 0400 hrs.) smolts moving out of Seton lake are delayed and no compensatory movement over the spillway seems to take place (Fretwell and Hamilton 1983). The quantitative impact of this on sockeye production has yet to be determined. A new turbine runner was installed by B.C. Hydro in 1977 but the impacts of this on smolt mortality were not appraised.

SALMON MANAGEMENT REQUIREMENTS

Few other hydroelectric developments in B.C. have received as much detailed fisheries research and management attention as has Seton. Reasons for this include the strategic location of the development at the confluence of a large river-lake system with the Fraser River, the abundant pre-development salmon stocks, the high profile given the development by the IPSFC during the project planning stages, and the undertaking given by the electrical utility during project licensing to address any problems occurring during plant operations. Initial operating constraints (included in the water licence) were relatively simple and specified only minimum discharges within Seton Creek at certain times of the year. Since then the constraints have become more specific, based on research, application and monitoring of results.

In 1975 DFO requested modified discharges to counter the serious sockeye mortalities and delays at the power house tailrace. These were subsequently estimated to be about 25 percent of the combined Gates and Portage creek runs (IPSFC 1976). The recommendations included flows not less than 11.3 m^3/s (400 cfs) down Seton Creek from 20 July to 15 November, not less than 28.3 m^3/s (1000 cfs) when salmon were present in the tailrace, not less than 5.7 m^3/s (200 cfs) after migrations, frequent plant shutdowns between 0600 and 1800 hours when Seton Creek flows were 28 m^3/s or higher, and a safeguard against leakage through the turbine wicket gates. These steps reduced impacts considerably, but did not eliminate them.

In 1977 B.C. Hydro encountered problems in meeting fish flow needs. Lengthy shutdowns were tried instead of increased flows to improve the economics of power generation and loss, but this caused storage problems in Carpenter Lake and plant operations at Seton had to be resumed. The shutdowns were not effective in reducing tailrace mortality in 1977, and only continuous discharges of 28 m^3/s down Seton Creek were judged to be useful for impact mitigation (DFO 1978a).

By 1985 the operating constraints to facilitate adult salmon passage past Seton Dam specified a minimum spill discharge from 20 July to 15 November of 11.3 m^3/s (400 cfs) during which time the plant was to be shut down or operated near full load. Cayoosh Creek contributions to Seton flows were to be limited to 20 percent during the Gates Creek migration (20 July to 31 August) and below 10 percent during the Portage Creek migrations (28 September to 15 November) to ensure that migrating sockeye were attracted to Seton Creek and the fishway over the dam. Air injection into the draft tubes was requested during plant shutdowns to depress water surface elevations to prevent fish ingress to the draft tube. Operation of the radial gate was restricted to a maximum of 28 m^3/s, except when all siphons were already operating, to minimize impacts on migrating sockeye and spawning pink salmon in Seton Creek.

Recommendations in 1986 and subsequent years have followed the same pattern, e.g. a 11.3 m^3/s minimum spill, temporary diversion of Cayoosh Creek water into Seton lake during key salmon spawning periods, and restrictions on spill limits for short- term periods (DFO 1987b). At the present time temporary diversion of Cayoosh Creek combined with minimum specified flows through the fishway sluice is regarded as the most practical solution to the problems of adult sockeye delays in the powerhouse tailrace and may be implemented on a permanent basis. A permanent diversionary structure for Cayoosh Creek would be an effective step in long-term management of salmon passage problems at Seton.

The problems with smolt passage through the power turbines and impingement on trashrack debris remain to be overcome. Studies in 1978 (Fretwell 1978) indicated that plant shutdowns were of no use in facilitating downstream passage unless accompanied by sufficient releases at Seton Dam (20 m^3/s or more). The problem is currently being approached from a fish behavioural standpoint (B.C. Hydro, pers. com.). Recent studies at Seton (Patrick and McKinley 1987) have indicated that strobe lights and sound deterrents (pneumatic poppers and hammers) may be effective in directing fish away from intakes. Implementation of such techniques as a permanent approach to directing smolts away from the power canal intake has yet to be considered.

SHUSWAP RIVER

PROJECT

Description

The project was constructed by the West Canadian Hydro Electric Corporation in 1929, and consists of impounded storage in Sugar Lake controlled by the Peers Dam at Brenda Falls, and the Wilsey Dam located 31 km further downstream which supplies Shuswap Falls generating station (Figure 25). Shuswap

Falls, about 26 m high, is located 23 km above the mouth of Mabel Lake. The project draws all its water from the Shuswap drainage basin (about 1130 km^2 in extent upstream of Sugar Lake). Sugar Lake has limited storage capacity (169 x 10^6 m^3, B.C. Hydro n.d.) and no full flow control capability. Present operating constraints on the dam relate to flood control and optimum water storage for electrical generation, with no provision for control of water for salmon requirements.

Wilsey Dam is a concrete arch structure 30 m high and 40 m long, and was designed as a run of river project for the minimum historical discharge of about 15 m^3/s (500 cfs), and a maximum operating load at about 35 m^3/s (1250 cfs). Retention behind the dam is thus limited to a small headpond 150 m wide and 350 m long. Storage was once approximately 154 x 10^6 m^3 and drawdown was usually about 8 m. Both storage and drawdown have been drastically reduced by large amounts of deposited sediment in the headpond. In 1942 the plant was enlarged by 3.5 MW, although its load capacity remained the same.

Water Licences and Operational Constraints

The water licence for the initial development permitted maximum storage in Sugar Lake of 24.7 million m^3, and diversion at the Wilsey Dam of 10 m^3/s (350 cfs) for power generation. Following plant refurbishment in 1942 the allowable storage was increased to 123.4 million m^3 and the allowable diversion to 14 m^3 (500 cfs). There are no provisions in the licences for release or control for fishery purposes.

Electrical Generation

Since 1951 Shuswap Falls has been used as a small baseload plant. The amount of power generation varies considerably because of variations in water availability in Sugar Lake and frequent plant shutdowns due to a variety of causes (see below). Between January 1984 and June 1987 monthly generation ranged from about 1.1 million kWH (28 percent capacity) to 4.7 million kWH (120 percent capacity), with a monthly contribution of 0.1 percent or less to the B.C. Hydro integrated hydro-electric grid system.

Enhancement Facilities

No fisheries enhancement facilities were developed by the utilities who have owned and operated the Shuswap plant. Planning of a hatchery located at Shuswap Falls was commenced by DFO in 1981 (DFO 1981) with the objective of providing chinook and coho outplantings in both the middle (i.e. above and below Wilsey Dam) and lower Shuswap River. A pilot hatchery was developed through 1984, with cooperation and building facilities from B.C. Hydro, and an experimental facility was completed in 1986 (Rosberg and MacKinlay 1987). The 1987 and 1988 stocking programs for the middle and lower Shuswap tributaries were based on provision of chinook, coho and rainbow trout from the hatchery. B.C. Hydro has indicated concerns for potential conflicts between the developing program and the power plant, i.e. passage of juveniles through the powerhouse and adults returning to the tailrace (DFO 1982).

A fish ladder was proposed for the Sugar Lake dam when the Shuswap Falls plant was built (1929) but was apparently not carried through because of lack of funds and disinterest on the part of DFO at the time (Starr 1978).

FLOW REGIME

Pre-impoundment discharge data from the Sugar lake outlet are of short duration and insufficient for a detailed comparison with the post-impoundment data. Pre-and post-impoundment data for the WSC gauging station below Shuswap Falls (Figures 26 and 27) show that mean maximum monthly discharges from January through March have been increased by about 50 percent through releases of water from Sugar lake. Monthly mean and minimum discharges have been unaffected, typical of a small run of river plant with limited headpond storage. Short-term flows in the Shuswap River have been significantly affected by sudden plant shutdowns (see below).

Sugar Lake is utilized as storage for the Shuswap Falls power plant, and monthly and daily releases (Figure 28) show considerable variation. The high variability in water releases through Peers Dam could be expected to lead to high variability in wetted areas, flow velocities and other salmon habitat parameters along the 32 km reach between Peers and Wilsey dams.

HABITATS

Below Impoundment

A detailed survey of the Shuswap River habitats between Sugar and Mabel lakes was made in 1984 (Fee and Jong 1984). The 15.2 km reach from Sugar Lake to the Cherry Creek confluence has a moderately high gradient (0.6 percent) and a confined channel. Resulting habitats are composed mainly of fast riffles and runs. Mean surface velocities are estimated to exceed 1.0 m/s, and 23 percent of the area is usable by salmonid juveniles during low flows. Only the stream margins appear usable at higher flows. The 13.1 km reach below the Cherry Creek confluence has transitional gradients and the channel is moderately confined with a small number of side channels. The latter comprise the most important rearing habitat. Stream side cover is good. The reaches are used extensively by rainbow trout. The 3.7 km reach above Wilsey dam is a low canyon and is subject to backflooding from the headpond. About 50 percent of the reach is deep pools and glides, and most of it is silted due to the low current velocities.

The 19.1 km reach below Wilsey Dam is wide and unconfined. Habitats are complex because of stream instability, and there are extensive side-channel habitats. About 73 percent of the side channel areas have velocities <0.4 m/s suitable for juvenile salmon rearing. The extensive gravels are rated as good spawning habitat for chinook, coho, sockeye and kokanee (Fee and Jong 1984). The 4 km reach above the Mabel Lake inflow has very low gradients (0.07 percent), extensive uniform meandering glides, very fine substrates and no pools, and is generally unsuitable for spawning, adult holding or rearing. The total stream area in the Middle Shuswap from the Sugar Lake outlet to the Mabel Lake inlet varies from 237 ha at October low flows to 336 ha at July moderate flows (Fee and Jong 1984). Current velocities permit rearing in 30 ha below the falls and in 13.5 ha above the falls. Suitable rearing cover (from log debris) covers 13,000 m^2 below, and 4100 m^2 above the falls.

Shuswap River water pH ranges from 7.5 to 7.9, has low specific conductivity, hardness, nitrite/nitrates and dissolved nitrogen, and moderate levels of total phosphate (Fee and Jong 1984). Mean water temperatures in July are about 15.5° C, and 10.5° C in September, which compares favourably with other good salmon rearing areas such as the Adams River (Fee and Jong 1984).

No information is available on the habitat conditions within the 60 km reach of the Shuswap River above Sugar Lake. Salmon are presently excluded from this section by both the Wilsey and Peers dams, but may have used the upper river if they were observed to enter Sugar lake (see below).

Above Impoundment

No information on the physical and biological systems of the Sugar Lake reservoir are available. The lake probably supports populations of mountain whitefish, rainbow trout and other resident salmonids (B.C. Hydro n.d.). Its capability to support anadromous salmonids (assuming access through Peers Dam is possible) is unknown.

SALMON POPULATIONS

Historic Populations

Chinook reportedly spawned upstream of Wilsey Dam prior to its construction in 1929 (Fee and Jong 1984) and so Shuswap Falls was only a seasonal fish blockage. Brenda Falls at Sugar Lake may have been an historical blockage to anadromous salmon at some times (Fee and Jong 1984) although sockeye in large numbers were reported ascending into Sugar lake and beyond in the 20's and 30's (IPSFC 1977). Wilsey Dam presently constitutes a total block to migrants.

Escapements

The Shuswap River historically has been an important production system for chinook, coho and sockeye. Chinook and coho have gradually declined (Figure 29), possibly the result of distant impacts such as over--fishing, as well as local impacts such as pollution and deforestation, leading to siltation of spawning areas. Sockeye have increased in numbers in the Middle Shuswap below the falls, probably as a result of protection and enhancement in other parts of the whole Shuswap River and lake system.

Nearly two-thirds of the Middle Shuswap River between Mabel and Sugar lakes was cut off from anadromous salmon access by the Wilsey Dam, hence overall escapements must have been drastically reduced. Only post-impoundment escapement data are available (Figure 28), and some of the sharp declines in chinook and coho escapements may have been due to previous impacts of desilting and dredging activities at the Shuswap Falls plant (see below).

Besides anadromous salmon, the Middle Shuswap River below Shuswap falls supports a kokanee population. Annual spawning populations recorded from 1954 to 1963 ranged from 9400 to 51,000, spawning from late September through early October. In 1977 DFO introduced 70 adult chinook above the Wilsey Dam on a trial basis (Fee and Jong 1984). Spawning of the chinook was noted, although no records exist for any subsequent results of the trials. The experiment was repeated in 1978 with only 3 females. The reintroduction of chinook is not considered potentially harmful to resident rainbow trout, provided food supplies are abundant (Griffith 1979). A pilot hatchery was built at Shuswap Falls in 1984 and an experimental facility completed in 1986 (Rosberg and MacKinlay 1987). The objective is to enhance chinook, coho and rainbow trout stocks throughout the Shuswap River system.

Spawning and Rearing

Present salmon spawning areas in the Middle Shuswap are limited to a 10 km section below Shuswap Falls (Brown et al. 1979a). Sockeye spawn from the falls to 1 km below the Bessette Creek confluence (Bowman and Stewart 1984). Chinook spawn in greater numbers in the reach immediately below the Wilsey Dam. Kokanee are reported as spawning throughout the 9 km reach below the dam, and much use is made of secondary channels (Bowman and Stewart 1984).

The Middle Shuswap River below the falls supported 75,000 juvenile chinooks in July and 10,000 in September 1983 (Fee and Jong 1984). Chinook juveniles occur in low to moderate densities during moderate flows in July. As flows decline later in the year and the water becomes clearer, so chinook move to highly specific habitats associated with cover (log debris) and deep water. Very few chinook smolts were found from the Middle Shuswap River in 1984 (Bowman and Stewart 1984). The 1984 fall coho juvenile population was estimated at 8000, giving 3500 smolts (Fee and Jong 1984), but very few chinook smolts were found from the Middle Shuswap River in 1984 (Bowman and Stewart 1984). Both chinook and coho are much more abundant in the Lower Shuswap River below Mabel Lake, and the Middle Shuswap is regarded as underutilized. Kokanee juveniles occur mainly in shallow side channels and side pools.

Rearing chinooks, coho and other salmonids make use of Bessette Creek which joins the Shuswap below the falls, although low summer flows in Bessette Creek are limiting to juvenile salmonids. Other salmonid juveniles in the system include rainbow trout, mountain whitefish and Dolly Varden. Tributaries above the Falls also support rainbow trout. The dominant salmonid throughout the Middle Shuswap is mountain whitefish (Fee and Jong 1984).

Migration of chinook smolts out of the Middle Shuswap likely occurs prior to April or during peak flows in June. Sockeye outmigration takes place from mid- to late May, and the coho outmigration period is probably from the end of May to early June. (Bowman and Stewart 1984).

PROJECT OPERATIONAL IMPACTS

Minimum Flows

The pre-impoundment discharge records (Figures 26 and 27) are too short to permit detailed analyses but mean annual, maximum monthly and maximum daily flows appear to have been little altered by hydroelectric regulation. Minimum monthly flows are considerably more erratic from year to year, and minimum flows in any one year have been generally lower since impoundment and regulation. The pre- versus post-impoundment comparison indicates high variability in monthly and daily discharges. Low flows have not been reported as limiting below Shuswap Falls, but this is likely due to the very low numbers of juveniles rearing in the section through the low flow periods (Fee and Jong 1984, Bowman and Stewart 1984). Flows in Bessette Creek are limiting to rearing populations in late summer, and the same conditions might eventually prevail in the lower reaches of the Middle Shuswap if salmonid enhancement leads to higher rearing populations.

Flow Fluctuations

Due to the plant design, all river flows < 35 m^3/s (1250 cfs) are directed through the turbines during operational periods. If a fault occurs, the turbines automatically shut down and water is held back until spilled. Due to the small capacity of the headpond it takes only minutes before spillage over the spillway occurs. Over a 4-year period (1975-1979) plant shutdown occurred automatically 35 times, and more than 50 percent of the shutdowns were accompanied by spills (B.C. Hydro 1979). The most common causes of shutdowns are low pressures in penstocks, high thrust bearing temperatures, creep detector warnings, and lightning strikes. Changes in water levels below the dam following a shutdown have been measured at 0.7 m within 20 minutes (DFO 1978b). Such short-term fluctuating flows are considered more damaging than low flows (Fee and Jong 1984) and have been observed to lead to extensive stranding of fry and adult fish, although no estimates of mortality have been made. Because of the short- term nature of the fluctuations and the availability of side channels and pools below Wilsey Dam, it is unlikely that shutdowns have caused major impacts, e.g. loss of an entire year class, but they are likely responsible for significant losses in juveniles and possibly adults. The mountain whitefish populations upstream of Wilsey Dam are reported to have been severely depleted by channelization and sudden fluctuations in water levels (DFO 1971).

DFO have made numerous representations to B.C. Hydro on the desirability of reducing the incidence of Shuswap plant shutdowns. No information is available to indicate whether the incidence of shutdowns has decreased over the years. Because of the advanced age of the installation and the plant it is likely that shutdowns would increase over time, rather than decrease.

Siltation

The forebay of Wilsey Dam has proven susceptible to siltation because of its small pondage. Silt accumulation requires removal approximately once every 5 years. Prior to the 1970's this was achieved by closing off Sugar lake and letting the headpond at Wilsey Dam draw down so that all flow was directed through the sluice gates. Silt deposits were mobilized by bulldozers, if necessary. The result was a massive flushing and dumping of silt on spawning areas below the falls (DFO 1970). The silt typically had a high organic content and a corresponding high biological oxygen demand, and may have given rise to toxic hydrogen sulphide concentrations (DFO 1971). Actual impacts to rearing fry and incubating eggs have not been monitored but are considered to have occurred through suffocation, direct lethal effects and the fluctuating levels associated with desilting (DFO 1971). The normal time of sluicing for silt was March to April which conflicted directly with fish life cycles.

Following representations to B.C. Hydro, suction dredging during freshets (mid-May to end June) was used since 1971 to control siltation. This has not proven cost-effective in removing the accumulated silt and a clamshell dredge has been used through the late 1980's (B.C. Hydro, pers. com.). B.C. Hydro are presently addressing the problems of large amounts of bedload entering the headpond and sediments flushing through the turbines causing mechanical damage.

SALMON MANAGEMENT REQUIREMENTS

B.C. Hydro have modified their desilting techniques at Wilsey Dam in an attempt to reduce downstream impacts. Siltation of gravels is likely a prevalent although unquantified condition in the Shuswap River due to continued intensification of land use adjacent to the river, deforestation, urbanization, etc. Both Peers and Wilsey dams have likely reduced the overall incidence of silts in the Middle Shuswap as much as they have contributed to sporadic problems with silt releases.

A major continuing impact of the plant on anadromous salmon is the high variability in flows, due in part to frequent plant shutdowns but mainly to the specific design of the development, i.e. storage in Sugar Lake and the generating plant located 32 km further downstream. Reducing the incidence of plant shutdowns is not easily dealt with, since these are mainly the result of wear and tear on the aging plant installation. Such interruptions are likely to increase in frequency. Further work on the installation is likely in the near future with potential impacts from construction and repair work.

A major impact of the development on salmon resources is the exclusion of adult spawners from the 30 km reaches above Wilsey Dam, and the 60 km reach above Sugar Lake. Habitat quality in the reach below Peers Dam is sufficiently good for serious planning of outplantings of chinook and coho (Fee and Jong 1984). No information on the Upper Shuswap River is available, but it was likely used within historic time by salmon who moved through Sugar Lake.

The Shuswap development was conceived and constructed at a time when concern for salmon escapements and habitats was not a matter of priority due to the perceived abundance of these resources. This is no longer the case, especially with species such as chinook which are declining due to a variety of causes, including habitat impacts. It is unlikely that serious consideration would be given today to development of such a project which provides a maximum capacity of 5.2 MW (0.06 percent of B.C. Hydro's total hydroelectric capacity), but which excludes salmon from almost 40 percent of the stream habitats in the Shuswap drainage. Efficient long-term management of the Shuswap watershed for its considerable salmon potential will inevitably require that the ancient Shuswap falls plant be removed.

CAMPBELL RIVER

PROJECT

Description

The Campbell River hydroelectric development

(Figure 30) consists of three impoundments plus a number of diversions which supply water to the storage reservoirs. The lowermost dam in the series is John Hart which was built in 1947 and which impounds John Hart Lake. Above it is Campbell Lake which was formed by the Ladore Dam, completed in 1957. The uppermost Strathcona Dam was completed in 1958 and impounds Upper Campbell Lake which is connected to Buttle Lake. The storage capacity of Upper Campbell Lake is 870 million m^3, and Campbell Lake has 319.5 million m^3. John Hart Lake has the smallest amount of storage capacity at 1.5 million m^3. Upper Campbell Lake receives water from the Heber River diversion, while the Salmon River diversion and the Quinsam River diversion supply water to Campbell Lake.

John Hart is a concrete gravity dam 20 m high and 200 m long with a concrete spillway and three sluice gates. A 1 km long flume leads water to the powerhouse sited on the bank of the Campbell River about 3 km further downstream. The John Hart generating station has a nameplate capacity of 120 MW, while those of Ladore and Strathcona are 54 MW and 67.5 MW respectively.

From 1970 through 1973 a proposed expansion to John Hart was studied, with alternative possibilities of either increasing the powerhouse size or constructing new (some underground) facilities. These schemes have been held in abeyance since 1977. The dam was extensively repaired from 1986 through 1988.

Water Licences and Operational Constraints

The water licence for the John Hart scheme permits a maximum diversion of 114 m^3/s (4074 cfs). No flow restrictions are appended to the water licences, but informal agreements (DFO 1966, Operations Control Department, B.C. Hydro, pers. com.) provide for minimum flows of 33 m^3/s (1200 cfs) and preferably 50 m^3/s (1800 cfs) and a maximum of 120 m^3/s (4300 cfs).

Electrical Generation

The three Campbell River plants together generate from 60 million to 140 million kWH per month, and contribute up to 5 percent of the provincial hydroelectric energy. The schemes are operated as combined baseload and peaking plants, and outputs vary from near zero to more than 100 percent of plant capacity. There is an hydraulic imbalance between the three developments, the John Hart plant having the lowest capacity, and a consequent need to frequently spill water from John Hart Lake.

Enhancement Facilities

No enhancement facilities were offered during development of any of the Campbell River schemes. Side-channels for chinook, chum and steelhead, located below the powerhouse were designed in 1984 (DFO 1984) and had been partially implemented by 1988 (J. Wild, DFO, pers. com.).

FLOW REGIME

The flow regime within the 5 km river reach between John Hart Dam and the river mouth is totally controlled by releases through the dam and powerhouse. Daily discharges through the turbines from January 1984 through December 1987 (Figure 31) ranged from about 50 to 110 m^3/s (1700 to 3900 cfs). Spill releases in 1986 and 1987 were sudden, and ranged from zero to as high as 340 m^3/s (12,000 cfs) within the space of a few days.

The relationships of dam discharges to salmon habitats within the Campbell River system below John Hart Dam were investigated in detail by Hamilton and Buell (1976). Discharges below 70 m^3/s (2500 cfs) were found to reduce available spawning habitats, expose redds, reduce available rearing areas and reduce protective production areas for most species. Discharges above 100 m^3/s (3500 cfs) reduced spawning areas, dislodged and depleted benthos and supportive organic detritus, scoured out gravels and limited rearing habitat. Releases from the dam from 1984 through 1987 (Figure 31) were outside of these limits on at least 50 percent of days. In addition, large rapid fluctuations in discharges were found to disrupt spawning salmonids, displace juveniles, deplete benthic insects, and cause stranding of rearing juveniles (Hamilton and Buell 1976). Fluctuations in discharge are a common occurrence in the Campbell River system.

HABITATS

Below Impoundment

The lower Campbell River is about 5 km in length from the John Hart Dam to the river mouth, ranges in width from 40 to 100 m, and is generally swift flowing. Prior to construction of the John Hart Dam, the Elk Falls were a natural blockage to anadromous salmon (Hamilton and Buell 1976). The present limit to upstream migrations is the pool below the John Hart tailrace. The Campbell River is generally deficient in spawning gravels because of a lack of supply from the upper watershed due to impoundment and fluctuations in discharge which have washed out gravel substrates (Hamilton and Buell 1976).

Salmon rearing habitats are limited in the lower Campbell River, which leads to most coho and chinook depending on the Campbell River estuary for rearing habitat. The river is considered to have a sub-optimal food supply, and a lack of adequate protective cover vegetation (Hamilton and Buell 1976).

Above Impoundment

No detailed studies of the Upper Campbell lakes have been undertaken since earlier surveys and assessments of the effects of lake storage (McMynn and Larkin 1953). Fishways into the storage reservoirs do not appear to have been considered as management or enhancement options.

SALMON POPULATIONS

Historic Populations

The Campbell River system, despite its relatively short length accessible to anadromous salmon, was one of the most productive salmon river systems on Vancouver Island. This was due to the biologically productive estuary, and the availability of spawning and rearing areas within the Campbell River itself and in the Quinsam, a major tributary. All five Pacific salmon occurred in the system in large numbers as did steelhead and sea-run cutthroat trout.

Escapements

Escapement records (Figure 32) indicate that chinook spawners in the Campbell River system have declined within the past 15 years and now number only 1000 to 2000 per year. The causes for the decline are complex and involve both local and distant factors. Impacts from the highly variable regulated hydrological regime have likely played some role. Coho have never been numerous in the Campbell River system and are generally more abundant in the tributary Quinsam system. Chum salmon escapements have declined to about 5000 per year and pink salmon to about 1500 per year. The dates of the declines of both chum and pink salmon show some correlation with the date of commencement of operations of the John Hart development (Figure 32).

Spawning and Rearing

Chinook spawn in the Campbell from mid-October through mid- November, and prefer fast riffle areas and the edges of runs (Hamilton and Buell 1976). The main chinook spawning areas are located below the tailrace and opposite the Elk Falls pump house. Fry emergence takes place from late February to early March, and fry rear for up to 3 months in the river before moving to the estuary, where they remain for about 3 months before finally moving into deeper water. Coho migrate into the system from mid-September to mid-November and peak spawning takes place from early October through November but continues until January. Fry emergence takes place at the end of March, and some fry are believed to move directly out to the estuary. The majority rear in the river for a year, however, and move out in April and May of the following year as smolts (Hamilton and Buell 1976).

Chum salmon migrate in and spawn from mid-October to the end of December. Chum generally prefer coarser substrates. Emergence occurs in March and April and fry move immediately out to sea. Pink salmon enter from August through September, and spawn from mid-September to early November. Emergence occurs in January and early February, followed by out-migration to the estuary. Sockeye have never been abundant in the Campbell River, probably due to the absence of lake rearing habitats. The few sockeye in the system probably rear in the river for variable periods before moving to the estuary.

PROJECT OPERATIONAL IMPACTS

Most of the impacts identified in the project expansion studies (Hamilton and Buell 1976) are likely occurring on a continual basis due to the operational mode of the John Hart plant. Water depths and velocities are likely frequently beyond the tolerance range of adult spawners and lead to a limitation on the amounts of spawning area available. Spills are still occurring within the spawning periods of chinook, coho, pink and chum salmon and are likely inhibiting the extent and success of spawning. The rapid fluctuations still prevalent in the system are probably causing stranding and flushing out of juveniles, especially coho, and the flooding of preferred rearing areas. Mortalities of incubating eggs and alevins due to substrate erosion by the sudden high spill discharges may also be a significant limitation.

SALMON MANAGEMENT REQUIREMENTS

Flow stabilization and the avoidance of spills is the single most important management measure to be implemented in the Campbell River system. The existing hydroelectric developments are poorly designed from the perspective of maintaining flow stability, however. Although B.C. Hydro would strongly resist attempts to adjust the storage rules for the reservoirs because of the loss of energy potential and a reduction in the peaking capacity of the plants, there would appear to be some value in examining alternative operational strategies for the whole Campbell River hydroelectric system. The objective should be to make use of storage in projects elsewhere on Vancouver Island and in the overall electricity grid to reduce discharge fluctuations at John Hart.

QUINSAM

PROJECT

Description

The Quinsam project (Figure 33) consists of a dam at the outlet of Wokas Lake and a 5.5 m diversion dam 1 km further downstream, which diverts water to Gooseneck lake and then to Snakehead Lake, Miller Creek and into Campbell Lake for electrical generation thorough the Ladore and John Hart generating stations (Figure 30). The diversion dam is equipped with a spillway and spill gates. The total Quinsam River drainage is 209 km^2 in extent, and the Quinsam is the major tributary to the Campbell. Major tributaries of the Quinsam River are the Iron River, Cold Creek and Flintoff Creek. The project was placed into operation in 1956.

Water Licences and Operational Constraints

The initial water licence in 1956 authorized the B.C. Power Commission to store up to 12.3 million m^3 of water in Wokas Lake and to divert up to 148 million m^3 per annum. The determination of the amounts to be diverted was to be made in consultation with the Minister of Fisheries. The initial request from the B.C. Power Commission (prior to design completion) was for 8.5 m^3/s (300 cfs, = the maximum capacity of the diversion canal) but this was opposed by DFO. Following extensive reviews and discussion the project was redesigned and licensed to divert a maximum of 4.7 m^3/s (165 cfs) in 1958, with provision for release of 1.7 m^3/s (60 cfs) through the sluice gate for fishery purposes between 1 September and 15 November (Comptroller of Water Rights files). DFO found these releases to be insufficient to safeguard the salmon resources, and by 1957 had agreed with the B.C. Power Commission on a continuous 0.6 m^3/s (20 cfs) release plus guaranteed storage for fishery purposes in Wokas and Upper Quinsam Lakes (the lowermost 0.6 m). This was again amended in 1963 to permit releases of 1.7 m^3/s (60 cfs) from February through May and from 1 September through 15 November each year, and for minimum flows of 0.3 m^3/s (10 cfs) for the remainder of the year. No further changes have been documented.

Electrical Generation

The Quinsam diversion generates no power directly, but supplies the Campbell lake system which generates power at Ladore and John Hart generating stations.

Enhancement Facilities

DFO established a hatchery on the lower Quinsam River some 3 km above Campbell River which commenced operations in 1974. From 1978 a program of planting of pre-migrant coho and steelhead fingerlings to otherwise inaccessible reaches in the upper Quinsam watershed has been followed. Smolts then migrate seaward through Middle and Lower Quinsam lakes. Recent surveys of the area found most upper watershed lakes and streams heavily utilized by planted fish (Blackmun et al. 1985). Rearing ponds were added to the Quinsam hatchery in 1984. Pink salmon enhancement levels for the lower Quinsam River by 1987 had reached 4.5 million fry released (DFO, pers. com.).

FLOW REGIME

There were no long-term flow data for the Quinsam River when the diversion was planned and constructed, and flow estimates were made from correlations with a 38-year record on the Campbell River. The mean annual daily low flow through the inlet on Middle Quinsam Lake was estimated at 1.1 m^3/s (40 cfs) and the mean annual low flow at 1.7 m^3/s (61 cfs) which was subsequently used as the basis for establishing flow release to the downstream reaches for fisheries purposes (Comptroller of Water Rights files). The post-diversion mean annual flow near the Campbell confluence has been measured at 9.2 m^3/s (Inland Waters Directorate 1988). Annual mean and monthly minimum flows have remained within a fairly narrow range (Figures 34 and 35) due to closely controlled releases through the sluice gates. Quinsam River flows near the confluence (WSC gauge 8HD005, Figure 34) are frequently very close to the minimum required in the water licence (1.7 m^3/s) which refers to the minimum flows in the river immediately below Lower Quinsam Lake. This suggests that minimum flows in the latter occasionally fall below 1.7 m3/s when inflows to the lake are insufficient to maintain such flows (as permitted in the conditional water licence). Flows in the Quinsam River are highly variable and flooding still occurs in the lower reaches, despite the presence of the diversion.

HABITATS

Below Diversion

Fish habitats within the Quinsam River have recently been surveyed by the Ministry of Environment (Hawthorn 1984). Some additional survey data are available from studies done for the Quinsam coal project (Norecol 1983) which is planned for the region surrounding Middle Quinsam Lake.

The Quinsam River below Wokas Lake is a 10 m wide stream flowing within a confined channel and over a 2 percent gradient. The substrate comprises cobbles and large gravels. Below the small diversion headpond the valley and channel are wider (15 m) but the gradient steeper (2.6 percent). Below Middle Quinsam Lake the channel enters a canyon in which substrates are cobbles and large gravels. This reach has numerous cascades, each 50 to 60 m long and 4-5 m high, and a few side channels, important to rearing salmonids. The most significant feature is a 15 m waterfall which is impassable by anadromous salmonids and marks the upper end of the 38 km stretch of the river accessible to spawners. Below the cascades the channel broadens to 20 m and flows through a wide valley with a gradient of only 0.7 percent. Above the Iron Creek confluence the channel enters a marshy area of low gradient and silty substrates. The river below Quinsam Lake has a 1.4 percent gradient with gravel substrates and exposed bedrock. Numerous cascades in this reach are passable by salmonids only during periods of high discharge. The terminal 8 km portion of the river is a low gradient stream with a large proportion of fines in substrate.

Middle Quinsam Lake, below the diversion, is a shallow basin with a maximum depth of 15 m, although most of the lake is <6 m deep and the western half is <4 m deep (Hawthorn 1984). The lake has rocky shorelines, submerged logs from previous logging activities, and has only low to moderate fishery habitat values. The eastern and western portions of the lake support extensive stands of aquatic macrophytes and are more productive habitats for fish.

Quinsam River water has a pH ranging between 6.8 to 7.6 and is very low in suspended material (Blackmun et al. 1985), but can become very turbid following storm events (Lukyn et al. 1985). Chemical water quality does not appear to limit salmon populations. Water temperatures in Middle Quinsam Lake reach 22° C in mid-summer (Blackmun et al 1985) which may be deleterious to rearing salmonids and which are nearly 4° C higher than temperatures in the lower Quinsam River (Figure 36). Dissolved oxygen concentrations below Middle Quinsam Lake drop to near 77 percent saturation in summer and remain in the high 90's for the rest of the year (Blackmun et al. 1985).

No habitat inventory data are available for the reaches through which the diverted water flows to the Campbell lake system. The general lack of good salmon spawning habitat in the upper Quinsam River area was a key factor in decisions not to invest in fishways during the development of the Quinsam diversion project.

Above Diversion

No habitat inventory information is available for Wokas Lake. There are no ladders permitting entry of salmonids to Wokas Lake.

SALMON POPULATIONS

Historic Populations

Pink, chum and chinook have historically used the lower reaches of the Quinsam River above the Campbell confluence. Coho, steelhead and some chinook were recorded as early as the 30's reaching as far as the falls below Quinsam Lake (DFO 1944). Steelhead and coho have been occasionally reported as ascending the falls into Middle Quinsam Lake. In the fall of 1942 many thousands of coho were observed immediately below the falls (DFO 1944). No mention is made of sockeye occurrence in earlier records.

Escapements

All five Pacific salmon species occur in the Quinsam River (Figure 37). Coho, chinook and pink salmon declined markedly during the late 60's and 70's, most likely due to heavy commercial harvests and habitat impairment, although no specific deterioration is reported for Quinsam River habitats, despite the diversion of water for power purposes and the increasing extent of logging and mining activities. Coho and chinook escapements have increased in recent years due to hatchery enhancement, and about 60 percent of present escapements are of hatchery origin (Shardlow et al. 1986).

Coho enter the spawning areas throughout the 38 km accessible reach below the falls in mid-October. Peak runs are observed in mid- to late October, but sometimes as late as late November. They are present in the river until mid-December. Coho require 1.7 m^3/s (60 cfs) for the in-migration period from 1 September through 15 November. This equates to about a 1.1 m^3/s release through the diversion dam. In 1957 a measured flow of 0.8 to 1.0 m^3/s at the cataracts in the lower Quinsam River prevented coho and pink salmon from moving further upstream. The B.C. Power Commission increased flows to about 1.6 m3.s and coho subsequently negotiated the falls. Increases in flows were too late in timing for the pink salmon to respond.

Pink salmon enter the lower Quinsam River from early to mid- September, and commence spawning by mid-September. Large numbers spawn during the last week in September, but peak spawning can extend to mid-October in some years. Pinks have been recorded in the Quinsam River below Cold Creek in mid-September with the recorded flow below Quinsam Lake gauged at 1.4 m^3/s. No extensive data are available for chinook, chum or sockeye escapement timing.

Spawning and Rearing

Coho juveniles dominate in samples taken throughout the Quinsam River system (Hawthorn 1984, Norecol 1983), including the diversion canal. Cutthroat trout are prevalent, but less abundant, and rainbow trout are common in the lower reaches. Coho juveniles also dominate in samples from Middle Quinsam lake. (Blackmun et al. 1985). About 50 percent of outplanted coho fingerlings appear to survive to the smolt stage (Blackmun et al. 1985). No estimates have been made for coho incubation or rearing flow requirements.

The major pink salmon spawning grounds are located between the Elk River Timber and the Argonaut bridges, and pinks do not generally move above the lower 10 km of the river. Some 260,000 m^2 of wetted area are available, of which 30,000 m^2 are used intensively by spawning pinks at spawning depths of 15 to 20 cm.

Most coho smolts moving out of Middle Quinsam and other lakes in the area (Blackmun et al. 1985) have been found to do so from early April to the end of May, with a peak out-migration in the second and thirds weeks of May. Out-migrations of coho from other parts of the watershed probably follow the same timing. There are no data available on out-migrations of other salmon species.

PROJECT OPERATIONAL IMPACTS

Minimum Flows

Low flows during the mid- to late summer period have proven to be the most important impact of the Quinsam diversion on salmonid resources, although no estimates of mortalities in rearing juveniles or in-migrating adults have been made. Between 1956 and 1966 B.C. Hydro frequently did not meet the minimum fishery requirements in the lower Quinsam River (1.7 m^3/s), and actual flows were measured at anything from 5 to 60 percent of the minimum requirement; the most seriously deficient period was from July to September (DFO 1969). Examination of the summarized flow data for the lower Quinsam (Figures 34 and 35) indicate that this condition may still occur due to very low flows into Upper Quinsam Lake in late summer. The impacts of these flows on salmon production have not been determined.

In 1968 the Greater Campbell River Water District applied for a licence to extract water from the lower Quinsam. The application was strongly opposed by DFO on grounds of insufficient existing water in the system for salmon.

Reduced flows in the lower Quinsam River may not be only the result of the diversion to the Campbell system. Extensive logging in the area over the years has been reported (DFO 1962b) as reducing storage and retention and increasing evaporation losses.

Water Temperatures

The effects of high water temperatures on rearing and migrating salmonids are usually strongly correlated with low summer flows. Summer water temperatures in the reaches below the diversion are high enough to be of potential concern (Figure 36), although no detailed studies of actual losses to production have yet been attempted.

SALMON MANAGEMENT REQUIREMENTS

Additional releases of water through the diversion dam sluice gates would reduce the downstream summer water temperatures, but the actual amounts required have not been determined. Requests for additional water do not appear to have been made within the past 20 years. The wording of the existing water licence provisions is such that it appears to permit additional releases to overcome such impacts (if they are occurring), provided such water comes from the lower 0.6 m of storage in Wokas Lake reserved for this purpose.

SALMON RIVER

PROJECT

Description

The project consists of a wooden crib diversion dam on the upper Salmon River, Vancouver Island, which diverts flows from the Salmon River and Paterson Creek via a flume into the outlet of Brewster Lake and then on to Campbell Lake below Strathcona Dam (Figure 30). The scheme was constructed from 1956 to 1958. There is no power plant on the Salmon River, and diverted flows are used to generate power at Ladore and John Hart generating stations. The impoundment dam has minimal storage capacity.

Water Licences and Operational Constraints

The conditional water licence entitles the holder to divert 493 million m3 water per annum. A clause stipulates that a flow of at least 2.8 m^3/s (100 cfs) be maintained at the WSC gauging station above the Memekay River confluence from 20 August to 15 November and that at least 2.4 m^3/s (83 cfs) be maintained at the same location for the remainder of the year. In addition a minimum flow of 0.14 m^3/s (5 cfs) is to be maintained at all time below the point of diversion. All flow releases are subject to the water being available in the natural flow of the river. The fish release specifications were developed by DFO in collaboration with the B.C. Power Commission. Stipulations were based on mean seasonal minimum monthly flows.

Electrical Generation

The diversion contributes to power generation through the Ladore and John Hart power station on the Campbell River.

Enhancement Facilities

No facilities were provided by the utility as mitigation or compensation. The Salmonid Enhancement Program has planted coho in many areas throughout the upper and middle Salmon watershed, using the Quinsam hatchery as a fry source.

FLOW REGIME

Only post-diversion flows have been monitored at the WSC gauging station above the Memekay River (Figures 38 and 39). Pre-diversionary discharges, including those on which the water licence requirements were based, were computed from correlations and extrapolation from Campbell River records.

The Salmon River discharges are highly erratic because of the elevational gradients within the watershed, heavy winter rainfall and relatively low summer precipitation. Post-diversionary flows have probably added an element of stability to downstream discharges, but have not overcome any low flow problems in summer, nor diminished the incidence of flood freshets, many of which originate below the diversion.

HABITATS

Below Diversion

Until 1980 the Salmon River was accessible to anadromous salmon for a length of 38.5 km (Ptolemy et al 1977). Boulders, bedload debris and log obstructions were major obstacles to salmonid migrations until removed over a period of 5 years, thereby adding some 12 km to the usable habitat within the system. Habitats below the diversion dam are used mainly by coho and steelhead (B.C. Hydro, pers. com.).

The Salmon River is wide (up to 50 m), deep (>2 m), and is slow moving in lower reaches (Ptolemy et al 1977). The upper reaches have high gradients, confined widths, shallower depths and faster current velocities. Substrates are gravels/cobbles throughout, with some boulders and bedrock segments. Very large amounts of organic debris have accumulated in the river. Gravel movements are common due to the frequent freshets. The lower river channel is unstable, with relatively large channel shifts and braiding.

Riverine habitats are pool-riffle and riffle-glide (Ptolemy et al 1977). Stream cover is limited in the lower reaches. Limitations to salmon rearing include bedload movements, lack of cover and bank erosion.

Salmon River water is low in conductivity, total alkalinity and total hardness, and pH varies from 6.7 to 7.4. Cold water temperatures may be a significant limitation to salmonid productivity (B.C. Hydro, pers. com.).

Above Diversion

Stream habitats above the B.C. Hydro diversion are morphologically similar to those immediately below the structure (Ptolemy et al. 1977). Grilse Creek is regarded as especially valuable steelhead rearing habitat and plans to enhance the reach through nutrient enrichment are currently being prepared (B.C. Fisheries Branch, pers. com.). About 20 percent of useful steelhead habitat within the Salmon River system lies above the diversion.

SALMON POPULATIONS

Historic Populations

All five species of Pacific salmon occur in the salmon River drainage, and were formerly much more abundant than at present (Ptolemy et al. 1977). Kokanee salmon were present in some headwater lakes.

Escapements

All five Pacific salmon species occur in the Salmon River watershed, but sockeye are seldom reported and occur only sporadically. Chinook escapements (Figure 40) have declined over the period of record, as they have in many other Vancouver Island river systems. There is no apparent correlation between escapement declines and the development of the Salmon River diversion, but this may be obscured by many other factors. Coho escapements (Figure 40) have similarly declined, to only 10 to 20 percent of their former numbers. The Salmon River is an important steelhead producer (Ministry of Environment 1988).

Spawning and Rearing

Chinook, chum and pink salmon spawn in the lower reaches only, in sections with low gradients. Coho reach the canyon 38 km from the river mouth, but chinook, pinks and chum seldom occur further upstream than about 15 km from the mouth, and the major pink spawning areas lie in the lower 12 km of the river which is subject to sudden heavy freshets (Ptolemy et al. 1977).

PROJECT OPERATIONAL IMPACTS

Passage of Downstream Migrants

A smolt screen was installed at the diversion in 1984 to permit passage of steelhead and coho smolts down the Salmon River (Ministry of Environment 1988); no information is available on the efficacy of this.

Blockage of Upstream Migrants

The diversion now blocks off some 70 km of usable upstream habitats. The possibility of a fishway past the diversion for steelhead and salmon is being studied by B.C. Hydro, DFO and MOE (B.C. Hydro, pers. com.); flow release requirements for fish passage below the diversion were studied in 1990 and 1991.

SALMON MANAGEMENT REQUIREMENTS

A similar situation to the Bridge River prevails in the Salmon drainage. Salmonid populations and habitat have suffered multiple impacts from logging and hydroelectric development, and a watershed management approach is required to rectify the issues. The correlations between declines in chum and pink salmon with the development of the Salmon diversion may be significant.

B.C. Hydro has abided by the water release requirements in the water licence. No firm evidence is available that flow regulations have been responsible for salmon declines, except possibly in the case of chum salmon. The system would benefit greatly from improved flow management to reduce freshets, flooding and erosion. The recommended flows in the water licence were designed primarily to meet requirements for spawning and rearing, and no information on incubation requirements is available.

HEBER RIVER

PROJECT

Description

The project consists of a low diversion dam across the upper Heber River to the west of Strathcona Park in central Vancouver Island (Figure 30). The flows are diverted into the Drum lakes and from there into the Elk River and then to the upper Campbell Lake reservoir. No documentation is available on the design of the diversion dam. The diversion was brought into operation in 1956.

Water Licences and Operational Constraints

The water licence entitles the holder to divert 111 million m3 water per annum. A clause requires the licensee to release enough water for "fish propagation" in the Heber River. This was established in 1971 (order attached to Water Licence), following earlier metering and surveys by DFO (1958a) to be not less than 0.6 m^3/s (20 cfs) as measured at the falls in the Heber River near the highway bridge crossing.

Electrical Generation

There is no generation plant on the Heber River and all diverted water is routed through the Campbell lakes system to generate power at the Strathcona, Ladore and John Hart power plants.

Enhancement Facilities

No salmon enhancement facilities were incorporated in the construction of the diversion.

FLOW REGIME

There is no WSC gauging station on the Heber River, and the nearest gauge is on the Gold River, of which the Heber is a tributary. Releases from the diversion are fixed, and the only major tributary below the diversion is Saunders Creek (estimated high discharge about 3 m^3/s), hence summer flows in the Heber River are likely very low.

HABITATS

Below Diversion

Useful salmonid habitat in the Heber River is restricted to a reach of some 10 km length above the Gold River confluence (DFO 1957). Substrates in the lower section consist of gravel pockets and many boulders, and the stream channel is largely confined. Two canyons (300 m and 1.5 km above the Heber-Gold confluence) contain falls from 1 to 3 m in height and are likely barriers to species such as chum and pink salmon. Approximately 11 km above the Gold River confluence is a fall of about 4 m height which probably constitutes a total barrier for upstream fish migration. No habitat inventories appear to have been made for the Heber River.

Above Diversion

No information available.

SALMON POPULATIONS

Historic Populations

There are no known historic records on salmon populations in the Heber River system.

Escapements

Escapement data are not available for the Heber River. Runs of all five salmon species occur in the Gold River with about 10,000 sockeye, 2000 chinook, 1200 coho, 500 pink and several hundred chum salmon being counted in 1986 (DFO escapement files). Because of the steep gradients and numerous falls in the Heber, it is likely that only coho make substantial use of the system. Steelhead occurred in fair numbers throughout the Heber River up to the falls about 11 km from the Gold River confluence (DFO 1957).

Spawning and Rearing

No information available.

PROJECT OPERATIONAL IMPACTS

Existing minimum flow releases to the downstream Heber River (0.6 m^3/s continuous) were established by DFO in 1971, based on field reconnaissance and estimates of average minimum annual flows in the river. No specific gauging of flows was done. The minimum release is only about 4 percent of the estimated late fall - early winter flows, hence low flow constraints on coho rearing are possible.

SALMON MANAGEMENT REQUIREMENTS

Any management of the Heber River for increased salmon production should realistically be based on management of the Gold River system. Available habitats appear suitable only for coho, and then only in relatively small amounts. In comparison to other regulated rivers in the province, the Heber is a relatively low priority system for investigation and enhancement.

PUNTLEDGE RIVER

PROJECT

Description

The Puntledge River diversion project was first developed in 1913 by Wellington Collieries Ltd to supply electricity to coal mines in central and eastern Vancouver Island. An impoundment dam was constructed at the outlet of Comox Lake (Figure 41), which has a drainage basin of some 450 km^2. About 4 km further downstream was a diversion structure which led water for 5 km via wood-lined flumes and stave pipes to powerhouse on the bank of the lower Puntledge River. The initial plant capacity was 7 MW although this much power was never generated. A fishway into Comox Lake was installed as part of the original project.

The B.C. Power Commission redeveloped the dams and powerhouse from 1953 to 1956 and increased Comox Lake storage from 54 million to 85 million m^3. They planned initially to use all 28 m^3/s (1000 cfs) permitted in the existing water licence. DFO strongly opposed any such uses because of the high salmon values of the system, and the reconstructed project was accordingly scaled down to use lesser flows (see below). The present project consists of a 10 m high, 100 m wide concrete and earthfill dam at the outlet of Comox lake equipped with gated sluiceways and an overflow spillway. The diversion dam is a 3.5 m high, 30 m long, concrete structure with a 2.5 m by- pass channel and a maximum spill capacity of 340 m^3/s. Both dams were furnished with rebuilt fish-ladders in 1955-56.

Water Licences and Operational Constraints

The original Wellington Collieries licence was for 28 m^3/s (1000 cfs) maximum diversion, but the maximum actually used did not exceed about 8.5 m^3/s (300 cfs). The licence was transferred to the B.C. Power Commission and then to B.C. Hydro. Considerable discussion and some experimentation with flow releases down the Puntledge River from 1956 to 1964 has led to agreements between DFO and B.C. Hydro regarding flow releases. The present agreements, dating back to 1965, deal separately with the upper river, between the diversion dam and the powerhouse, and the lower river below the powerhouse (Figure 41).

The flow requirements during the 1960's and 70's were documented by DFO (1974). The required minimum flow in the Puntledge River channel below the diversion dam from June to August was 5.7 m^3/s (200 cfs) for the benefit of the summer-run chinooks) and 2.8 m^3/s (100 cfs) for the rest of the year. The specified minimum flow below the powerhouse, including the inflows from the Brown River, was 21 m^3/s (725 cfs) at all times. If DFO considered it necessary to minimize injuries in the tailrace, a shutdown of the power plant could be ordered. From 1963 through 1965 a total shutdown was effected during June and July and the plant operated on a 12-hourly basis only (0600-1800 hrs) during August.

The above formal agreement between DFO and B.C. Hydro has been informally modified in attempts to benefit both fisheries and power generation. From November through February the 2.8 m^3/s minimum flow below the diversion dam is in effect and provides barely adequate coverage for summer run chinook spawning. From March to mid-June, B.C. Hydro provides flows of 5.7 m^3/s below the diversion and draws down Comox Lake (if refill forecasts favourable) to reduce the incidence of freshet flows in the lower river and to benefit rearing conditions for chinook and other fry. From mid-June to mid-August, the plant is operated at reduced loads to minimize adult injuries at the tailrace, and flows below the diversion are increased to 8.5 to 14 m^3/s (300 to 500 cfs) to minimize pre-spawning adult injuries at Stotan and Nib falls. After mid-August when summer-run chinook have completed their in-migration, DFO normally agrees to reducing flows to 7 m^3/s (250 cfs) to reduce draws on Comox Lake. B.C. Hydro usually requests that flows in the lower Puntledge River be reduced below the agreed minimum of 21 m^3/s (725 cfs) to conserve water in Comox Lake. Mid-September to mid-October minimum flows of about 4 m^3/s (140 cfs) are required to operate the rearing channel effectively, and to provide for summer-run chinooks holding in the channel or in the diversion pool below it.

Due to the limited active storage in Comox Lake combined with series of dry summers in the 1980's it was difficult to provide sufficient flows in the lower river during the fall spawning period. In partial response to this issue DFO conducted studies to confirm the amount of spawning habitat versus flow at a number of locations in the lower river in 1989. These data demonstrated that 21 m^3/s was needed to flood the important side channel spawning grounds located in the lower river. To better guarantee sufficient flows during the early fall spawning period DFO and B.C. Hydro have agreed to manage reservoir releases via the use of a rule curve. The rule curve incorporated hydrographic information from the years on record and the required spawning flow of 21 m^3/s on 15 September (needed for pink salmon spawning). By tracking changes in lake elevation throughout the year compared to the historic data it was possible to determine if lake elevations were sufficient to meet target flows or if changes in power production or discharge were required in order to meet the requirements. As it happened 1989 was the driest late summer - early fall on record and the spawning flow goal was not met (even though rearing flows were decreased below optimum once it became clear that problems were developing and that water had to be conserved for the fall spawning period). However, the fall flow situation would have been worse if the rule curve approach was not adopted

Electrical Generation

The Puntledge generating plant presently has a nameplate capacity of 27 MW. Actual power generation at the plant varies considerably from month to month and within any one period according to peak power demands and the highly variable nature of the storage available in Comox Lake. Some degree of variability in power generation is caused by the flow constraints due to fisheries needs. Between January 1984 and June 1987 monthly power generation ranged from zero to 19 million kWH (100 percent capacity), with contributions to the B.C. Hydro hydroelectric grid ranging from zero to 0.7 percent.

Enhancement Facilities

Following redevelopment of the Puntledge project in 1955, DFO requested salmon enhancement facilities to compensate for the various impacts. Following lengthy negotiations involving hearings before the B.C. Energy Commission (B.C. Hydro 1962), B.C. Hydro contributed to building and maintaining a chinook spawning channel adjacent to the diversion dam in 1965. In 1971, following poor results from the enhancement, B.C. Hydro contributed to building rearing ponds adjacent to the spawning channel. In 1979 the spawning channel was converted to an adult holding and fry rearing channel.

In 1977 DFO established a hatchery on the Puntledge River near Courtenay to build up fall-run chinook, coho and steelhead stocks through restocking throughout the watershed.

FLOW REGIME

The mean annual post-project discharge in the Puntledge River (gauged in the lower river near Courtenay) is 43 m^3/s (1500 cfs). The pre-project discharge record is relatively short (Figure 42), but appears to indicate little difference in terms of maximum and mean flows. Minimum flows, both monthly and daily, are more stable. The Puntledge River has a small watershed and low storage capacity (Comox Lake) in relation to total run-off and monthly and seasonal flow are highly variable (Figure 43). Minimum flows have been stabilized by the impoundment of Comox Lake.

Flood flows in excess of 28 m^3/s (1000 cfs) are known to cause migration problems for chinook at Stotan Falls, and the optimal flow is in the 10-20 m^3/s range.

HABITATS

Below Impoundment

Despite the high salmon resource values in the Puntledge River, there appear to be no detailed habitat survey data. Based on the seasonal distribution of spawners, the entire Puntledge River from the mouth to the diversion dam, with the exception of cascades and falls, appeared to contain high quality gravels at the time the hydroelectric project was refurbished (1953 to 1956). The amount of spawning gravels in the river has steadily declined since that time, allegedly due to seasonal freshets which have eroded the stream bed, with no replenishment from higher reaches (DFO 1974).

The 1.5 km reach above Nib falls commences at the diversion dam and contains extensive gravel beds still used by chinook. Nib Falls was impassable to salmon prior to construction of a semi-natural fishway in the early 1980's. The 2 km reach between Nib and Stotan falls contains patches of spawning gravels used intensively by chinook and coho. The 3 km reach above the powerhouse has a gradually declining gradient and is bounded at the upper reach limit by Stotan Falls which was impassable under low or very high flow (flood) conditions until construction of a fishway in early 1986 (DFO 1985). Migration baffles were installed at Lower Stotan falls in 1969 and Upper Stotan Falls in 1971, and a minimum summer flow established to allow chinook to negotiate the falls. The lowermost 4 km of river from the powerhouse to the mouth is a low gradient, moderate velocity reach, with some islands and small back channels and is the main spawning area for pink and chum salmon.

Above Impoundment

Early (1923 to 1930) attempts to stock the lake and the upper tributaries with sockeye salmon were unsuccessful (Burridge 1954) although the reasons for this were not clear. Comox Lake appears to be a normal productive lake (Burridge 1954), although no detailed limnological data are available. Due to the long-standing existence of the impoundment dam at the Comox Lake outlet, little interest was expressed in the use of Comox lake and the upper tributaries for salmon production until 1980 when coho fry were released into Comox Lake. This program has continued to the present (DFO, pers. com.).

SALMON POPULATIONS

Historic Populations

The Puntledge River supports all five Pacific salmon species, and is mainly valued as a production area for chinook, coho, chum and pink salmon. Coho were known to ascend into Comox Lake before the impoundment in 1913 (Burridge 1954) and it is likely that chinook did the same. Sockeye were planted annually in Comox Lake and the tributaries from 1923 to 1930 with minimal success. The lower Puntledge River was renowned as a spawning area for large concentrations of pink and chum salmon.

Escapements

The Puntledge River traditionally has had two runs of chinook - early and late. The early run commences in late May or early June and peaks in mid-July, while the late run enters the river in early September, with peak in-migrations from late September to early October. Late-run fish are typically much bigger than early run fish. Spawning of both runs takes place at the same time.

Annual escapement data indicate that chinook numbers have ranged from 1500 to more than 11,000 (Figure 44), but declined markedly after 1955 and have seldom reached above 1000 since then, despite the provision of a spawning channel in 1965 (since converted to a rearing and holding channel) and ongoing propagation attempts from the Puntledge hatchery. The greatest decline has been in fall-run chinook. The causes for the declines are complex and manifold, but the sharp drop following redevelopment of the Puntledge diversion and generating plant in 1956-56 (Figure 44) is probably significant. Cited causes include power generation activities and consequent flushing removal of gravels, egg mortality and loss of alevins, as well as earlier problems with passage up the river (due to flows too high or too low) and delays at the powerhouse tailrace (DFO 1974). A high incidence of mortality was recorded in chinook using the spawning channel in the late 60's and early 70's due to head injuries sustained during migrations though Nib and Stotan falls.

Coho enter the river from early September until mid-January, and congregate in deep pools below tributaries. Large escapements also move to Morrison Creek and the Tsolum River. Coho escapements have increased markedly since 1982 (Figure 44) due primarily to stock enhancement from the Puntledge hatchery.

Pink salmon enter the Puntledge River between 1 August and 31 October. Their main holding and spawning area is below the powerhouse. A proportion of the run, depending on its overall size, gradually moves up the river to Stotan falls and into the tributaries. Pink salmon escapement peaked at over 150,000 in 1951 (Figure 44) after which they collapsed and have never recovered their former numbers. Deterioration in the quality of the spawning gravels in the lower Puntledge due to outwashing by flood flows (see below) is often cited as a major cause of pink salmon decline. Pink salmon fry emerge in early April with a peak in mid-April and move directly to the sea.

Chum salmon enter the system from 15 September to 15 January, with main concentrations occurring between late October and mid-December. Most spawning activity is in the lower Puntledge River as well as in the Tsolum River and Morrison Creek. Chum escapements have varied over the years but have not shown the same declines as pinks or chinook.

Spawning and Rearing

Chinook spawning historically took place principally between the impoundment and diversion dams (Holden 1958). Some spawning took place within the spawning channel in the late 1960's but success was limited and in 1979 the channel was converted to an adult holding and fry rearing facility (DFO, pers. com.). Some chinook spawn below Stotan Falls, while small numbers were reported to negotiate the fish ladder and enter Comox Lake (Holden 1958). In 1963 a few chinook spawners were observed (DFO 1963) in the lower reach of the Cruikshank River (tributary to Comox Lake) and were assumed to have ascended the fish ladder. All chinook reaching the diversion dam are now captured and used as brood stock for hatchery operations. Chinook spawning extends from early October until the first week in November with a peak in mid-October. Spawning of both runs takes place at the same time.

Coho spawning commences in mid-October while the run is still migrating in. Peak spawning occurs shortly after flows rise in early November. Mainstem spawning occurs in the mainstem from Morrison Creek to Stotan Falls, although most spawning activity is in the tributaries. Coho fry rear within the river for a year following emergence in April, the numbers depending on the amount of rearing habitat available. This does not appear to have been quantified to date. Some fry may be flushed out of the lower river by flood peaks.

Pink salmon spawn mainly below the powerhouse and below Condensery Bridge as well as in the Tsolum River and Morrison Creek; they occasionally spawn as far up the river as Stotan falls and into some of the tributaries. Spawning commences mid-September, peaks in the last week of September, and is complete by mid-October. Chum salmon can enter the system from 15 September to 15 January, with main concentrations occurring between late October and mid-December. Most spawning takes place in the lower Puntledge River, and in the Tsolum River and Morrison Creek. Emergence and migration of chum fry is usually 3 weeks to 1 month behind that of pink salmon.

PROJECT OPERATIONAL IMPACTS

The Puntledge development was beset by considerable fisheries problems following its enlargement in the early 1950's, and a great deal of attention was paid to overcoming specific problems arising from salmon-hydroelectric power generation conflicts. Although not yet problem free, the present situation is a considerable improvement due to a workable flow release schedule and enhancement from the hatchery and rearing channel.

Delays at Tailrace

In late 1955 it was observed that chinook were unable to get past the powerhouse tailrace when power releases were about 25 to 30 m^3/s and river flows were less than 10 m^3/s (DFO 1955). Mortalities occurred due to trauma. Short-term releases of 11 to 17 m^3/s did not encourage chinook to move up river. In 1956 water releases plus power cut-backs were initiated to encourage chinooks past the tail-race, although results were mixed. A subsequent agreement between DFO and B.C. Hydro provided for reduced plant operation from mid-June to mid-August to minimize adult injuries at the tailrace, and increased flows below the diversion (8.5 to 14 m^3/s). In the mid-1980's gratings were installed at the powerhouse draft tube outlet to exclude salmon spawners. These measures appear to be generally effective, although tailrace injuries are known to still occur.

Blockage and Delays at Falls

Delays at Stotan and Nib falls were, in earlier years, a major problem for chinook and other species (DFO 1974). Significant delays, especially at Nib Falls, were probably a recurring problem before the hydro-electric impoundment was developed. Apart from delays in reaching the upper spawning areas and the spawning channel entrance, serious injuries occurred to pre-spawners on the trashrack of the diversion dam and while attempting to negotiate the falls. Earlier recommendations were for flows less than 7 m^3/s and greater than 4 m^3/s to facilitate migrations. Present agreements allow for flows below the diversion of 8.5 to 14 m^3/s during summer migrations to minimize chinook pre-spawning adult injuries at Stotan and Nib falls. In addition , concrete baffles have been installed at Stotan and Nib falls to create more favourable passage conditions.

Mortality through Powerhouse

Prior to the construction of the spawning channel in 1965, mortality of out-migrating chinook and coho fry and smolts was a major problem. In 1956 fyke nets were used in the forebay to catch migrants and move them to the river below the powerhouse diversion (DFO 1959). Totals of 23,600 chinook and 13,800 steelhead fry were caught as well as smaller numbers of smolts and cutthroat trout fry. Capture success was estimated at 35 percent, and 46,500 fry were estimated to have been flushed through the turbines. In 1955 tests on downstream migrant fry estimated a 25 to 40 percent mortality through the turbines. Fry cannot be fished above the diversion during periods of high discharge.

In 1957 and 1959 tests with experimental louvres were undertaken at the diversion intake in attempts to find a permanent solution to juveniles being drawn through the powerhouse turbines (DFO n.d.). Efficiency of the louvres in deflecting smolts ranged from 60 to 90 percent, depending on approach velocities, louvre bar alignment and other test conditions. Louvres were considered too costly for implementation, however. In their place, the B.C. Power Commission contributed to the costs of building a spawning channel; this produced poor results and was converted to a holding and rearing facility in 1979. Louvres and/or screens were not considered again once the chinook spawning channel was constructed in 1965 since chinook were then prevented from entering the river above the diversion dam. Mortalities of coho smolts continue to occur in the power house in unmeasured but probably increasing numbers, correlated with the increasing numbers of smolts moving downstream from Comox lake where outplantings of fry have been taking place since 1980. Mortalities to steelhead smolts is likely to assume greater significance as enhancement takes place in the upper Puntledge watershed. In 1989 strobe lights and a water hammer were tested as devices to divert migrating coho fry out of the power canal, with unsuccessful results (B.C. Hydro, pers. com.). Results with an experimental electrical barrier tested in 1989 were also disappointing. B.C. Hydro is presently examining the feasibility of screens to divert smolts (and eventually fry) away from the penstock intakes (B.C. Hydro, pers. com.).

Loss of Spawning Habitat

Loss of spawning gravels due to frequent flood peaks has been indicated to be a major cause of loss of chinook and pink salmon spawning gravels in the lower Puntledge River and a contributory cause of the declines in these species (see above). The trend in flooding is likely to continue because of the basic design of the Puntledge hydroelectric scheme, i.e. the storage capacity of Comox Lake is small in relation to the watershed run-off and to the capacity of the power plant. Electrical power production efficiency necessitates keeping Comox Lake storage as high as possible until the fall rains, with a resultant increased danger of flooding and gravel washouts. In addition B.C. Hydro has to release water in October to December and April to May of most years to prevent upstream flooding. In 1989 a multipurpose spawning and rearing side channel, designed to operate at both high and low flows, was completed immediately upstream of the powerhouse. The facility was jointly funded and planned by B.C. Hydro, DFO, MOE and the Steelhead Society. A second side channel is planned for completion in 1991/92 (B.C. hydro, pers. com.).

Water Temperatures

Normal maximum water temperatures in the lower river and up as far as Stotan Fall are near 21° C in August. Flows are normally reduced markedly in August to conserve Comox Lake storage. No problems resulting from high water temperatures have been specifically identified, but temperature-induced stress may be a factor affecting coho juvenile survival in some years. Tailrace discharges may be cooler in hot weather and attract in-migrating adults.

SALMON MANAGEMENT REQUIREMENTS

The Puntledge situation is a good example of adaptive management, where ongoing studies, monitoring and innovative problem solving have reduced (but not eliminated) the impacts of a poorly designed and sited (from the fisheries perspective) hydroelectric plant. The most appropriate approach to the Puntledge problems is to continue the same strategy, with careful documentation and recording of results so that other problem situations involving hydroelectric installations can benefit. Monitoring of ongoing fisheries impacts from hydroelectric operations should be an integral part of the adaptive management strategy.

ASH RIVER

PROJECT

Description

The development consists of a 30 m, 185 m long, rock- and earthfill dam located on the Ash River at the outlet of Elsie Lake, central Vancouver Island (Figure 45). The main dam has a concrete weir spillway with a capacity of 1100 m^3/s but no outlets. Four separate saddle dams range in height from 3 to 18 m and width from 50 to 450 m. One saddle dam is equipped with a 2.5 m diameter reinforced concrete culvert which discharges into a channel leading into the main river channel. A 6.5 km power tunnel carries water to a power station of 25.2 MW capacity located on the northern shore of Great Central Lake. The project was completed in 1958.

Water Licences and Operational Constraints

The conditional water licence provides for maximum storage of 76.5 million m3 and a maximum diversion of 339 million m3 per annum. A mean minimum monthly flow of 3.5 m^3/s (125 cfs) is required in the Ash River near its confluence with the Stamp River for fisheries protection purposes. In addition the discharges from Elsie Lake may not be less than 0.7 m^3/s (25 cfs) from June through August, and not less than 0.3 m^3/s (10 cfs) at other times.

The conditional water licence (issued in 1956) also made provision for "fish collection works" at the power house on Great Central lake; this provision was apparently never implemented.

Electrical Generation

The Ash River generation plant is run as a baseload plant for most of the year, during which time generated capacity ranges from 18 million to over 21 million kWH per month, the latter generation being about 20 percent over the plant's maximum capacity as per the nameplate rating. Generation is cut back during the summer months to less than 50 percent capacity.

Enhancement Facilities

None associated with the hydroelectric project.

FLOW REGIME

There were no long-term gauging data available at the time the project was designed and constructed, and the discharges were computed largely on the basis of correlations. These estimates suggested that the annual mean minimum flows for the period 1914 to 1921 at the Ash River mouth were near 3 m^3/s, but DFO's estimates of minimum flows from August through October were about 9.5 m^3/s. Gauged flows from 1956 to 1958 below the dam site gave estimates of mean minimum flows of over 7 m^3/s, which were at the time considered the minimum required for optimal coho rearing in the mainstem Ash River.

Post-impoundment discharges (Figures 46 and 47) are characterized by highly variable maximum daily and monthly flows, but fairly constant minimum monthly and daily discharges in the Ash River near the confluence with the Stamp River. Flows in August and sometimes September decline sharply and consist entirely of the minimum fisheries flows released through the saddle dam outlet.

HABITATS

There are no habitat inventory data available for the Ash River or any of its main tributaries. At least one falls (Dickson Falls, 13 km above the mouth) occurs in the 20 km reach between the mouth and the Elsie Lake dam, and may be a significant salmon blockage.

SALMON POPULATIONS

Historic Populations

Earlier (pre-1958) DFO records judged the annual coho escapement to the Ash River to be about 1500. Steelhead were estimated to be about as numerous as coho. No mention is made of other salmon species within the Ash River but sockeye, chinook, chum and pink salmon occur in the Stamp River - Great Central Lake system.

Escapements

Escapement data have not routinely been collected for the Ash River system. Escapement data were collected in the 1930's and 1940's for tributaries of the Stamp and Somass rivers, of which the Ash River is a tributary.

Escapements to the Somass River (Figure 48) indicate a recent resurgence of sockeye and chinook stocks, probably due to enhancement efforts from the Robertson Creek hatchery (chinook) and fertilization programs in Great Central lake and Sproat Lake (sockeye). Coho escapements have dwindled in spite of propagation and enhancement of streams from the hatchery. Chum salmon stocks have declined and pink salmon no longer appear in escapement counts. Poor estuarine conditions due to pulp mill effluents are blamed for the demise of chum and pink stocks.

Spawning and Rearing

Coho spawning in the Ash River is reported to take place from 15 October to 1 January (DFO 1958b). The sites and extent of rearing are unknown. No information is available for the other species. It is unlikely that sockeye, chum or pinks would utilize the Ash River to any extent but conditions might be favourable for chinook.

Coho emergence is assumed to take place in May, and residence in the system for a year is likely, but no specific information is available.

PROJECT OPERATIONAL IMPACTS

The extent of the operational impacts of water storage in Elsie Lake and diversion to the powerhouse on Great Central lake has not been studied. The Ash River reaches above Elsie Lake total some 30 km and contain several small lakes; it is likely that these reaches were used by coho and possibly chinook before impoundment took place. The original project design called for collection facilities at the powerhouse for adult migrants (species not stated) attracted to the outflows, and the use of tank trucks to haul them to the Ash River. These facilities were apparently never developed.

B.C. Hydro has apparently complied with the provisions of the water licence in terms of minimum releases to the Ash River below the impoundment (Figure 46), but the extent of limitation of these flows, especially in late summer, on in-migrating and spawning stocks has yet to be established.

The total Ash River system comprises a fairly large proportion of the Somass-Stamp system which is a key west coast area for sockeye, chinook and coho, and there is likely a considerable production potential for these species in the system.

SALMON MANAGEMENT REQUIREMENTS

Any management of the Ash River for increased salmon production would realistically be accomplished as an adjunct to management of the Somass and Stamp systems. There appears to be much potential in the Ash River system, but the present limitation is a lack of site specific data on habitats and the existing impacts by the flow regime.

JORDAN RIVER

PROJECT

Description

The project consists of a hollow concrete dam 38 m high and 270 m long (Elliott Dam) across the Jordan River on the south-west tip of Vancouver Island (Figure 49). The dam is equipped with a 650 m^3/s capacity concrete spillway without any spill control facilities. There is a low level outlet with a maximum capacity of about 10 m^3/s. A diversion tunnel runs for about 9 km from the dam to a powerhouse situated at the mouth of the river. The nameplate capacity of the present generating plant, rebuilt in 1971, is 150 MW. The Elliott Dam was constructed from 1969 to 1971.

A short distance upstream are two diversion dams, the Jordan River (or Diversion) Dam and the Bear Creek Dam, both constructed from 1911 to 1913 and upgraded from 1969 to 1971, and again from 1985 to 1988 (Diversion Dam). These are 18 m high earthfill saddle dams with rock spillways and low-level outlets. None of the Jordan River dams have fish passage facilities.

Water Licences and Operational Constraints

The water licence entitles the holder (originally the B.C. Electric Company) to store a total of some 30 million m3 water per annum, and to divert a maximum of 10.4 m^3/s (366.6 cfs). There are no provisions for water releases for fisheries or any other purposes.

Representations by DFO at various times in the past (e.g. 1964, 1966) have led to B.C. Hydro agreeing to minimum flow releases of about 1 m^3/s (35-40 cfs) for fisheries purposes, but these have been short-term arrangements only, and the 1984 through 1987 flow release data for the Jordan plant show no such releases being made, presumably because there is no longer a viable salmon resource in the system.

Electrical Generation

From 1971 onwards the plant was used as a peaking plant, running to a maximum of about 300 hours per month. From 1984 through May 1987 electrical production from the Jordan River plant ranged from near zero to about 52 million kWH per month (about 46 percent capacity). Total monthly contribution to the provincial hydroelectric grid ranged from near zero to about 1.4 percent.

Enhancement Facilities

No salmon enhancement facilities were incorporated in the construction or redevelopment of the project. Following redevelopment of a new powerhouse in 1971 DFO requested construction of spawning channels (at B.C. Hydro's expense) but these were refused. Spawning channels have been considered as part of the Salmonid Enhancement program, but have yet to be investigated in detail (Salmonid Enhancement Program 1983).

FLOW REGIME

There is no WSC gauging station on the Jordan River. Examination of discharge data from the Jordan River plant for the period 1984 through 1987 (Figure 50) shows that the discharges through the turbines are very erratic, presumably following peak load generation demands. Discharges through the turbines ranged from zero to almost 60 m^3/s (about 2000 cfs) within the same month. There were no fish water releases for the same period, hence flows below the dam were extremely low during these periods.

HABITATS

No river habitat inventories appear to have been made for the Jordan River. It is unlikely that salmon occurred to any great extent above the sites of the existing diversions because of the relatively limited stream area available and the steep gradients in the area.

SALMON POPULATIONS

Historic Populations

There are no historic records on salmon populations in the Jordan River system.

Escapements

Escapement data for the Jordan (Figure 51) indicate that coho and chum salmon were present from the time of the first escapement counts, i.e. prior to 1930 but only in small numbers. Chum salmon then increased to a maximum escapement near 10,000 in 1952, after which numbers declined sharply during the 50's and neither species was recorded in the system after the mid- 60's. The declines preceded the redevelopment of the Jordan River installation and the commencement of operations of the larger powerhouse in 1971. The present river regime constitutes a hostile environment for salmon, so it is unlikely that re-establishment will occur under the present circumstances.

Pink salmon were not recorded in the first 20 years' escapement counts, and were recorded for the first time in 1952. They were recorded again from 1958 to 1970, and all were noted to congregate and spawn in the tailrace. In 1971 DFO requested compensation for the loss of pink salmon but B.C. Hydro refused on the grounds that the fish did not occur in the river prior to hydroelectric development (B.C. Hydro 1971).

Spawning and Rearing

About 4000 pink salmon were observed spawning in the tailrace and another 1000 in the river up to 500 m above the mouth in late 1964. From 500 to 800 pink salmon were again in the tailrace in September 1968 (DFO 1973). No information on spawning activity by other species is available.

PROJECT OPERATIONAL IMPACTS

Although it is not clear to what extent operation of the old Jordan River plant from 1913 onwards was responsible for the declines in coho and chum salmon in the lower 10 km of river, it is apparent that the highly erratic operation of the plant now precludes the restoration of natural salmon stocks in the system. Stranding of fish in pools below the main dam is reported to occur when the turbines shut down suddenly and presumably was an important impacting factor on salmon when they were present.

SALMON MANAGEMENT REQUIREMENTS

Although the system presently has no significant salmon resources, it is possible that the natural habitat capacity of the river may be subject to rehabilitation if major and frequent spills from the dam have not caused extensive erosion and outwashing of gravels. The storage capacity of the reservoirs is very limited, and so is the possibility of obtaining a more stabilized flow regime in the river below the dam. The most promising approach would be development of spawning channels, using a constant water supply drawn from the Elliott Dam headpond. Other possibilities include restoration of natural spawning runs in the river between the dam and the powerhouse by establishing a minimum release schedule. A problem with the Elliott Dam is that it is not equipped with a facility which can be easily controlled for water releases. A minimum requirement for management at the present time is a survey of the river below the impoundment and an assessment of its regenerative capacity for salmon habitat.

CHEAKAMUS RIVER

PROJECT

Description

The project consists of a 28 m high, 680 m long earthfill dam across the outlet of Daisy Lake on the Cheakamus River, approximately 20 km above the confluence with the Squamish River (Figure 52). The gated concrete spillway has a total capacity of 1400 m^3/s, and the dam has two radial gates, a low level sluice gate and a 0.7 m diameter hollow cone valve. A small turbine generator (150 kW) discharges to the Cheakamus River (about 0.6 m^3/s) and supplies local power to operate the sluice gates. A 11 km tunnel diverts water from Daisy Lake via Shadow Lake to a powerhouse on the upper Squamish River. The nameplate capacity of the generating plant is 140 MW. The Cheakamus project was completed in 1957.

Water Licences and Operational Constraints

The water licences permit B.C. Hydro to store a maximum of 55.5 million m3 of water, and to divert a maximum of 863.5 million m3 per annum. The licence contains provisions that flows must be maintained for "fish propagation" in the Cheakamus River. Downstream fish water flows are released through the hollow cone valve, the setting of which depends on the reservoir elevation and is determined by B.C. Hydro in consultation with DFO. The required downstream flows are documented as 14 m^3/s (500 cfs) below the Rubble and Culliton creek confluences (DFO 1980), i.e. B.C. Hydro is required to release water from Daisy Lake to supplement natural flows to this amount. Fish water releases to the downstream river from 1984 through 1987 ranged from 0.5 to 1.9 m^3/s (19 to 66 cfs)(see below);

Electrical Generation

Cheakamus is operated mainly as a peaking plant for loads in the lower mainland. The plant's monthly output from 1984 through mid-1987 ranged from near 9 million kWH (about 10 percent of capacity) to over 107.5 million kWH (>100 percent of capacity). Total contributions to the provincial hydroelectric grid ranged from 0.2 to 3.2 percent.

Enhancement Facilities

No enhancement facilities were developed by the proponent as mitigation or compensation for fisheries impacts. A spawning channel near Paradise Channel, a subsidiary channel to the Cheakamus River, was built by DFO in 1982 for pink, coho, chinook and chum salmon. The first phase of a hatchery on Tenderfoot Creek was completed in 1982 and the capacity doubled by the end of 1984 (MacKinlay 1985b). The hatchery is the present basis for chinook, coho and steelhead enhancement of the Squamish and Cheakamus river systems.

FLOW REGIME

The Daisy Lake storage reservoir has a licensed diversion capacity much greater than its storage capacity, and as a result the pre- and post-impoundment flows in the Cheakamus River below the Dam show little difference in maximum daily and maximum monthly flows (Figures 53 and 54). Mean flows were reduced by more than 50 percent, as were minimum monthly and daily flows, but the latter tend to be more stable due to the low-level releases. They are considered too low for optimal salmon rearing in the mainstem river (DFO, pers. com.). Flows in the lower Cheakamus in the 1970's were considered to be significantly less than 11 m3/s as required by the DFO-B.C. Hydro agreement (DFO 1980). Apart from the overall reductions in flows, the diversion dam has shaped the monthly flow pattern (Figure 55) by markedly reducing spring and fall flows.

Because of storage limitations in Daisy Lake, water is spilled every year (Figure 56). Spills normally coincide with the high run-off associated with melting snowpack in the mountainous watershed, but may also occur in winter due to very high precipitation. The flooding risks to mainstem salmon habitats in the Cheakamus and lower Squamish river valleys thus remain high, despite the presence of flow regulation.

HABITATS

Below Impoundment

The most valuable salmon habitats within the Cheakamus River system appear to be restricted to a 12 km reach above the Cheakamus-Squamish confluence. Above this reach a canyon section restricts access because of chutes and falls. There do not appear to be any detailed habitat survey data for the system, and most studies to date have been related to escapement checks (e.g. Demontier 1978).

Although not studied in detail, water quality in the Cheakamus River may have some effects on salmon production. Glacial silts enter the river via the tributaries and siltation of the Daisy Lake forebay is a continuing problem (B.C. Hydro, pers. com.), hence siltation of spawning gravels may be occurring. Decreasing water quality due to Whistler village sewage outfalls is now the subject of an ongoing monitoring program by EPS and other agencies (Environment Canada 1982). Late summer water temperatures in the Cheakamus River are generally 9.5° C or less (Demontier 1978) and no temperature related effects on salmonids have been documented.

Above Impoundment

Daisy Lake supports populations of rainbow trout and kokanee and is the basis for an important recreational fishery. There are no fishway facilities for salmon at the Cheakamus Dam. Water quality considerations in Daisy lake are currently the subject of an ongoing study program by the Environmental Protection Service and other agencies (Environment Canada 1982).

Historic Populations

All five species of anadromous Pacific salmon traditionally occurred in the Squamish and Cheakamus River systems in large numbers and were the basis for an extensive Indian food fishery which is still active at a reduced scale near Squamish (Hoos and Vold 1975).

Escapements

Sockeye are seen only in very small numbers in July in the Cheakamus River and appear to spawn mainly in the smaller creeks (DFO escapement files). Chinook enter the system as early as late June, with peak numbers usually evident in July and early August. Chinook escapements increased following regulation of the Cheakamus River by the Daisy Lake dam (Figure 57), but it is not clear if the correlation indicates a cause and effect relationship. Present winter flows are considered limiting to rearing chinook populations in the lower Cheakamus (DFO, pers. com.). Chinook have been artificially enhanced in the Cheakamus since 1982. Coho have declined in the system, despite enhancement from spawning channels and outplantings from the Tenderfoot Creek hatchery, although the full effects of such enhancement may not yet be apparent in escapement numbers. Coho migrate into the system in August. The causes for the decline in coho numbers are not apparent, although impoundment and reductions in mainstem rearing areas may have played some role. Pink salmon numbers reached high levels in the 70's and then crashed dramatically. The causes are unknown. Chum salmon, as with chinook, increased in numbers following the onset of regulation in 1957, and recent numbers are partially the effects of enhancement from hatcheries and spawning channels.

Spawning and Rearing

Most chinook spawning takes place in fairly restricted areas below the canyon, within 10-12 km of the Squamish confluence. Spawning extends through late August through mid-October. Chum salmon spawning is more widespread, and extends into the smaller tributaries to the lower Cheakamus and along the Paradise Valley channel (Demontier 1978). The few remaining pink salmon in the system spawn from late August through mid- October. Little information is available on salmon rearing in the system, but both coho and chinook appear to utilize the mainstem for rearing (DFO, pers. com.).

PROJECT OPERATIONAL IMPACTS

Fall and Winter Low Flows

Although no specific information on mainstem wetted areas, habitats and densities of incubating and rearing eggs and fry are available, it is highly likely that fall and winter flows are limiting to coho and possibly chinook populations. The regulated regime has reduced flows over this period by some 50 to 85 percent (Figure 55).

Water Quality

Siltation of habitats downstream from the dam is a possible but as yet unquantified problem. Construction activities at Cheakamus Dam have in the past contributed to siltation. On balance it is likely that the dam has reduced siltation levels due to retention of glacial and other silts originating above Daisy Lake. Late summer water temperatures in the Cheakamus River are generally 9.5° C or less (Demontier 1978) and there is no evidence that high summer water temperatures are a problem.

Downstream Flooding

The incidence and extent of damage to the salmonid habitats below the dam by frequent flooding has not been quantified but is likely a significant factor in reducing densities of rearing fry and/or causing mortalities in incubating eggs and alevins.

SALMON MANAGEMENT REQUIREMENTS

The Cheakamus River has considerable potential for natural salmon production in the mainstem and lower tributaries as well as associated production from the recently established spawning channel near Paradise Channel. Enhancement from the recently established Tenderfoot Creek hatchery is proceeding at an increasing pace (MacKinlay 1985b), but outplantings from the hatchery are being made into a system where flow conditions for salmon production are sub-optimal. Operation of the Cheakamus River hydroelectric development affects salmon habitats but the extent of this needs to be quantified before any steps to seek remedial actions can be attempted. The existing water licence provisions allow for the setting of flows for salmon protection. The major constraint on management at present is the lack of detailed reach-specific data on habitats, wetted areas, rearing densities, substrates types, and the relationships of these to discharges from the impoundment.

FALLS RIVER

PROJECT

Description

The project was built by the Northern British Columbia Power Company in 1929-30 and consisted of a 12 m high, 156 m long, concrete gravity dam located at the confluence of Falls River (Big Falls Creek) and the Ecstall River, located 25 km above the Ecstall-Skeena River confluence (Figure 58). The powerplant, located near the base of Big Falls, had a nameplate capacity of 3.2 MW, and the spillway had a maximum discharge capacity of 850 m^3/s. In 1960 an additional 3.7 MW unit was added. B.C. Hydro purchased the plant in 1964. The dam and spillway were recapped in 1981-83 and the operating level of the reservoir was increased slightly. The capacity of the plant was brought up to 9.6 MW.

Water Licences and Operational Constraints

The conditional water licence, issued in 1929, authorized the utility to divert a maximum of 17 m^3/s (600 cfs) and to store a maximum of 37 million m3. No provisions were made for fisheries or other purposes.

Electrical Generation

The Falls River plant is operated at a fairly constant monthly load, ranging from 45 to 70 percent of its capacity. Its contribution to the integrated B.C. Hydro grid averages about 0.03 percent.

Enhancement Facilities

None associated with the facility.

FLOW REGIME

See below.

HABITATS

The Falls River dam is located adjacent to the 50 m high Big Falls. The powerhouse discharges directly into a 180 m long tailpond which connects to the Ecstall River over a bedrock cascade. The tailpond is subject to strong tidal influence and at high tide the cascade is about 1.5 m under water (Lister 1981). At ebb tide the cascade is 4-5 m high and probably impassable to salmonids. Recorded discharges out of the tailrace range from zero to 566 m^3/s (Lister 1981). Salmon redds have been observed by divers within the tailpond (Lister 1981, Redenbach 1981) including the areas within the tailrace discharge and near the tidal rapids. The reservoir impounded by the Falls River dam is some 310 ha in extent and not accessible to anadromous salmonids.

SALMON POPULATIONS

Historic Populations

No records of historic salmon occurrence are available.

Escapements

Not recorded.

Spawning and Rearing

Field surveys associated with redevelopment of the Falls River project (Lister 1981, Redenbach 1981) noted very small numbers of chinook, coho and chum salmon within the tidal pool below the tailrace in August and September. Most fish sampled were immature. The only evidence of salmon breeding within the tidal pool is the redds observed by divers.

PROJECT OPERATIONAL IMPACTS

The area used by anadromous salmon and affected by the project is a relatively small tidal pool subject to the water velocity impacts of a 50 m waterfall and of relatively low value as spawning and rearing habitat. Overall operational impacts by the hydroelectric development are considered negligible (B.C. Hydro 1980).

SALMON MANAGEMENT REQUIREMENTS

There are no useful management measures for the immediate project area, considering its nature and limited habitat values.

MANAGEMENT OF SALMON RESOURCES IN REGULATED RIVER SYSTEMS

All new projects in B.C. presently require full environmental assessments and resource evaluation prior to construction, the purpose being to determine the full extent of the losses and to devise mitigation and compensation adequate to respectively reduce and recover the losses. This was not done in the case of many of the older hydroelectric projects described above due to different perceptions and sets of values in the times when these projects were planned and devised. Only six of the 16 projects which regulate anadromous salmon-bearing rivers had any fish-water release provisions included in their water licences (Seton, Ash River, Cheakamus, Quinsam, Salmon River and Heber River - Table 1). However, B.C. Hydro presently provides some form of flow releases for an additional eight projects, based on informal agreements with DFO (Coquitlam, Alouette, Stave, Ruskin, Wahleach, Shuswap Falls, Puntledge and John Hart - Table 1). There has been very little sustained follow-up and monitoring to check on the value of any released water in terms of salmon productivity in both types of cases, i.e. those where it is mandatory according to the water licence and those where B.C. Hydro has complied with specific requests.

The concept of "retro-active compensation" for older projects without adequate salmon fishery safeguards is not viable since it would likely have little basis in law or existing B.C. environmental procedures. However, several older hydroelectric installations continue to have significant impacts on present salmon resources which are of high value to the province and the national economy. Restoration of these resources, wherever feasible, should logically be provided, even though not required at the time of construction.

WATER RELEASES AND OPERATIONAL CONSTRAINTS

A review of rivers presently subjected to regulation by B.C. Hydro dams and diversions (Table 1) indicates that provisions in the respective water licences for water to be released for downstream fisheries uses appeared only after 1956. Hydroelectric developments planned and constructed prior to this date had no mandatory provisions for such releases. Nine of the 16 rivers regulated by B.C. Hydro which support anadromous salmon fall into this category. The lack of mandatory water release requirements for this large proportion of projects mainly reflects:

a. the attitude prevailing before the mid-50's that salmon resources were either unlimited or very resilient in their ability to withstand severe changes to their habitat through flow alterations; and

b. the advanced age of the some of the developments. Of the 20 B.C. Hydro dams and diversions which regulate the flows in rivers bearing anadromous salmon, 19 were first constructed at least 30 years ago, 6 were constructed at least 50 years ago and 3 are at least 60 years old. Many of the dams and power plants have been refurbished at various intervals in the intervening period.

Of the six projects which have specific release provisions specified in the water licences, only two (Seton Creek and Quinsam) have specific water release schedules and operational constraints which have been developed over a fairly lengthy period based on studies, observation and trial and error.

Similar release schedules have been developed for three projects without water licence requirements for such (Wahleach, Puntledge and Ruskin). Flow releases are now very important management devices at these installations to ensure adequate spawning habitats and passage through natural or man-made blockages. Control of powerhouse operations, i.e. shut-downs or restricted operational periods at certain periods has become an important management device in reducing impacts to adult in-migrating spawners at tailraces. A logical approach would seem to be to extend this adaptive management strategy to the other developments which present problems to salmon habitats and populations.

The situations prevailing at the projects where flow constraints have been imposed suggest that:

a. some, but not all, salmon production levels have been improved by imposition of operational constraints;

b. increased production has been almost always associated with enhancement from spawning channels or hatcheries;

c. a lack of satisfactory production cannot necessarily be ascribed only to water constraints or other operational impacts by the hydroelectric development. Other factors appear to play an important role, e.g. lack of spawning substrates at Puntledge.- Four installations (Salmon, Ash, Heber and Cheakamus) have requirements for water releases written into their licences, but there have been no site specific studies or investigations to determine the requirements of the salmon resources. The indications from trends in escapements are that salmon productivity in all four systems has declined.

Historical information on file suggests that in the past B.C. Hydro has been reluctant to implement specific actions involving the release of water. Reductions in the frequency of seasonal flooding, avoidance of sudden water fluctuations and increased releases of water at biologically critical periods have been the most frequently requested modification in operational procedures. B.C. Hydro's reluctance to comply with all requests for water releases and operational modifications stems mainly from three considerations:

a. hydroelectric developments are regarded basically as single-use projects, with other water resource uses such as fisheries or recreation of secondary value;

b. released water which is not used to generate power is considered to represent a real financial loss in terms of wasted energy potential and, explicitly or implicitly, B.C. Hydro is judging that any gains to salmon production are not worth these economic losses;

c. there is a reluctance on B.C. Hydro's part to release water for downstream fisheries uses into systems which are degraded from other impacts, e.g. urban encroachment or gravel removal.

ELECTRICITY GENERATION BY PLANTS ON SALMON-BEARING RIVERS

British Columbia's hydroelectric capacity was increased more than fivefold between 1960 and 1984 with the construction of mega-projects[1] such as W.A.C. Bennett Dam, Peace Canyon, Mica, Seven-Mile, Kootenay Canal and Revelstoke. Projects located on salmon-bearing rivers now make up only 14 percent of B.C. Hydro's total hydroelectric capacity compared to more than 90 percent before the mega-projects were constructed. B.C.'s total hydroelectric capacity jumped by almost 25 percent when Revelstoke entered production in early 1984. Growth in electrical demand has since reduced excess hydroelectric production capacity.

In the 4-year period January 1984 through December 1987 generating stations on salmon-bearing rivers in the Fraser River system, on Vancouver Island and along the B.C. coast produced about 15 percent of B.C. Hydro's electrical output (Figure 59) and about 18 percent of that produced by the mega-projects. Electrical production by all plants, including those located on salmon-bearing production rivers (Figure 60) varies considerably from year to year and month to month as a factor of available water supplies and fluctuations in load demands.

MANAGEMENT OF REGULATED SALMON RIVERS

In order to effectively manage and restore the salmon production potential of many regulated river systems in B.C. a number of major impediments have to be identified and overcome.

Problems of Predicting Results of Flow Improvements

A problem in pressing for more water and improved operating conditions to enhance downstream salmon habitats and populations is the difficulty in accurately forecasting the amount of improvement or the increased rate of production to be gained by such changes. Net salmon production, as measured by various parameters such as escapements, spawning success, egg to fry survival rates, adult return percentages, etc. are all affected by multiple factors, many of them far removed from the river system being managed, e.g. commercial and sport harvests, ocean survival, etc. In addition, the accuracy and reliability of the parameter most often used to measure the strength of salmon stocks in regulated rivers, i.e. escapement counts, are often questionable.

The suggested approach to overcoming this problem is one of adaptive management (Walters 1986) where a water budget or set of operating constraints are established first on the best- available information, and the results carefully monitored to check the extent of success or failure so that the release and operating schedules can be continually adapted or "fine-tuned" for better results. This has been applied in various forms to three of the plants discussed above - Puntledge, Quinsam and Seton - and is the logical basis for ongoing management and assessment of other systems. Abundance and production indices such as densities of rearing juveniles per unit wetted area can give an initial basis for estimating the likely gains from modifications to flow releases. Assessments based on production indices such as spawning or rearing would have to be the basis for an initial assessment and benefit-cost analysis of the value of water releases. The amount of error in the estimates would have to be taken into consideration so that even the worst case, i.e. the lowest likely improvements given a certain water release, would be reasonably close to the break-even point.

Realistic Valuation of Water Released for Salmon Benefits

A lack of agreement on a realistic price for water released to downstream fisheries uses is a major obstacle to progress in obtaining better flow conditions at existing B.C. Hydro hydroelectric installations. While water used for energy production should be realistically priced, its production potential for salmon should also be realistically estimated before any comparisons between fisheries and power uses are made. Pricing should reflect its full value to commercial, sport and native fisheries, the intrinsic value of the natural habitats (versus artificial spawning channels or hatchery facilities), and the value of the associated freshwater fisheries (a provincial responsibility). It should be noted that many of the hydroelectrically regulated rivers have long been deprived of the flows required to make them productive. These systems were not well studied nor appropriately valued at the time they were subjected to hydroelectric development, and more stringent criteria would be applied today in ensuring adequate water and discharge conditions for anadromous salmon (e.g. the Nechako system (Nechako Fisheries Conservation Program 1988)).

Establishment of Priorities and Common Bases for Regulated River Management

Management of regulated rivers could not realistically attempt to restore salmon resources back to what they were before development in every case. Too many changes, many of them not related to hydroelectric development, have taken place in regulated systems since they were first developed, e.g. urban encroachment, impacts from mining, etc. On the other hand, hydroelectric impoundment could enhance the downstream resources, e.g. by stabilizing flows or reducing risks of flooding in systems which were previously highly susceptible to natural floods (i.e. most B.C. systems).

The present institutional situation as it applies to the management of water in rivers regulated by hydroelectric projects is often characterized by a lack of focus. In the past many groups within DFO (e.g. habitat management units and divisions, regional divisions, fisheries officers, SEP) and outside DFO (e.g. IPSFC, Provincial Fisheries Branch) have made representations to B.C. Hydro for better water allocations for salmon and other fisheries purposes. These ventures have not necessarily been coordinated or even based on a common goal. B.C. Hydro has tended to respond to each request on a project-specific basis and has been reluctant to loose the potential energy by releasing water to downstream salmon uses without a convincing justification as to its values for such uses. DFO has frequently been equally reluctant to expend effort and money studying a system to acquire such information without any assurance that water would be made available if the information was available.

The solution to the problem is to establish common ground for dealing with regulated river systems by having a forum to deal with all regulated rivers, a *common* basis for valuing water for energy and fisheries uses, and a *mutually acceptable* set of priorities for overcoming existing salmon - flow problems[*1].

Based on the restoration and enhancement potential of the salmon habitats in the various regulated systems and the measures assumed necessary to restore or improve these habitats (Table 2), five groups can be established (Table 3). Cheakamus and Shuswap rivers are judged to retain a high potential for improvement with modifications to the present flow regimes. Puntledge and Bridge rivers also have high potential for improvement, but the measures to attain increases in habitat quality would be relatively more difficult and expensive because of the complexity of the situation (Puntledge) or the lack of a suitable design for flow releases (Terzaghi Dam on the Bridge River). Heber and Falls rivers probably have little potential for significantly improved habitat quality, and the available information on the Ash and Jordan rivers is inadequate to permit any evaluation. The remainder of the regulated systems comprise a group with moderate restoration potential where improved flow regimes would very likely lead to improved salmon productivity (over that which has already been attained) but where natural or other (urban, industrial, etc.) limitations would restrict the realization of much greater gains. The group with high potential includes Seton Creek and the Bridge, Shuswap, Campbell and Puntledge rivers. For all the systems of high and moderate potential, the intrinsic value of the downstream habitats (and possibly up stream habitats in the case of Shuswap), the present nature of the hydroelectric impacts, and the past successes (Seton and Puntledge) in adjusting the flow regimes all indicate a high probability of success in attaining increased productivity through flow modifications (listed in Table 2).

[*1] A Hydro-Fisheries Policy Committee established in 1988 (Ennis 1990) and representing DFO, MOE and B.C. Hydro now provides this forum.

RECOMMENDATIONS

The above review indicates that anadromous salmon resources within river systems regulated by B.C. Hydro dams and diversions are of considerable existing and potential value, but are continually being impacted by the operations of these hydroelectric installations. A number of actions are recommended to deal with the situation.

1. A process of adaptive management should be developed to gradually overcome present hydroelectric impacts within regulated river systems. Water budgets and operating constraints should be established on the best available information (or judgment and extrapolation from other areas if necessary) and the results carefully monitored to check the extent of success or failure so that the release and operating schedules can be continually adapted or "fine-tuned" for better results.

2. Rivers which should receive priority attention in establishing suitable water budgets and restoring more optimum flow conditions include Cheakamus, Shuswap, Puntledge, Bridge, Campbell, Quinsam, Stave, Seton and Alouette. Project-specific issues which should receive early attention include:

   a. monitoring of operational procedures and flow releases in order to adaptively improve these operations to the benefit of the salmon resource; results, successes and failures should be carefully documented so that other regulated river systems can benefit from the accrued experience;

   b. surveys of rivers such as Cheakamus and Bridge to determine an optimum flow regime for salmon protection and production;

   c. development of a suitable outlet at Terzaghi Dam for long-term use and a corresponding release schedule to allow for improved conditions in the downstream Bridge River;

   d. changes to the operational procedures for storage in Sugar Lake to reduce water level fluctuations in the Middle Shuswap River;

   e. revised operational procedures for Shuswap Falls power plant to minimize water level fluctuations and sedimentation below Wilsey Dam;

   f. consideration of the establishment of a fishway at Sugar Lake; and

   g. removal of the Shuswap Falls power plant and restoration of Wilsey Dam for fisheries management purposes.

3. B.C. Hydro should be urged to institute changes within their integrated production and supply system to allow for improved flow conditions in salmon-bearing rivers. Priority items which should be addressed include:

   a. changes in overall system operations to reduce production from plants on the most important salmon-bearing rivers and to compensate by increasing production by other larger plants which do not impact on anadromous salmon;

   b. establishment of modified rule curves for the management of storage in hydroelectric impoundments, including Comox, Coquitlam, Daisy, Alouette, Stave and John Hart lakes, to minimize water level fluctuations and the likelihood of unpredictable spills and flash floods in the downstream river systems

4. A more realistic approach to estimating the economic value of water released for fisheries purposes and lost for power generation needs to be developed. This should take into account the flexibility within B.C. Hydro's integrated system for supplementing energy in one region by energy from other regions and hydroelectric projects, plus B.C. Hydro's crown corporate responsibility in providing essential water for provincial and national fishery resources.

5. Realistic economic values for salmon habitats and populations need to be developed so as to estimate the economic extent of losses to these resources from hydroelectric operations.

6. Recognition should be given to the fact that salmon habitat management and restoration in most systems are complex procedures because of joint federal-provincial-industry-community interests and the extent of interacting and competing effects. These issues should therefore be addressed appropriately through the development of integrated resource management plans.

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Table 1. Water releases to salmon production rivers regulated by B.C. Hydro dams and diversions (March 1990).

River	Diversion / Dam (*1)	Licensed Diversion	Releases Required by Water Licence	DFO - B.C. Hydro Agreements	Optimum Release Schedule for Salmon Production	Released Water Availabl for Power Generation
Fraser River System						
Coquitlam	Coquitlam	82 m3/s	Nil	Occasional short releases for specific purposes	Not established (*2)	No
Alouette	Alouette	28 m3/s	Nil	0.06 m3/s continuous; 0.6 m3/s released for past few years	1.5 m3/s Oct-Apr 0.9 m3/s May-Sep Minimize fluctuations Reduce flood risks	No
Stave	Ruskin	60 m3/s	Nil	28 m3/s stable discharge during spawning	As per agreement to adjust flows supplying chum incubation channel	No
Wahleach	Wahleach	13 m3/s	Nil	0.8 m3/s during spawning, 0.4 m3/s during incubation 1.4 m3/s during migrations	As per agreement for production in spawning channel	No
Bridge River	Terzaghi	150 m3/s	Nil	Nil	Not established	No
Seton Creek	Seton	143 m3/s	11 m3/s during sockeye migrations, 5.5 m3/s at other times	See Appendix 1	As per agreement	No

Continued -->

Table 1 continued

River	Diversion / Dam (*1)	Licensed Diversion	Releases Required by Water Licence	DFO - B.C. Hydro Agreements	Optimum Release Schedule for Salmon Production	Released Water Availabl for Power Generation
<u>Fraser River System (continued)</u>						
Shuswap	Shuswap Falls (Wilsey Dam)	14 m3/s	Nil	Maintain headpond level at level of spillway crest to ensure prompt spill if powerplant fails; minimum flow of 22 m3/s maintained in 1989	Stabilize natural fluctuations; avoid sudden pulses in dam releases	Yes (except for Wilsey Dam spills)
<u>Vancouver Island</u>						
Campbell	John Hart	114 m3/s	Nil	33-50 m3/s min. 120 m3/s max.	70-100 m3/s Mar-Jun, Sep-Dec 55-120 m3/s Jul-Sep, Dec-Feb Restrictions on rates of flow change	Yes (powerplant No (spillway)
Quinsam	Quinsam Diversion	148 million m3 per annum	1.7 m3/s Feb-May 1.7 m3/2 1 Sept - 15 Nov, 0.3 m3/s rest of year, 0.6 m storage reserved in Wokas Lake	Nil	As per licence; 0.3 m3/s sometimes sub-optimal in August; releases for water temperature control not established	No
Salmon	Salmon Diversion	16 m3/s	2.8 m3/s make-up Aug - Nov, 2.4 m3/s make-up and 0.14 m3/s at diversion Nov-Aug	Nil	Not established	No

Continued -->

Table 1 continued

River	Diversion / Dam (*1)	Licensed Diversion	Releases Required by Water Licence	DFO - B.C. Hydro Agreements	Optimum Release Schedule for Salmon Production	Released Water Availabl for Power Generation
<u>Vancouver Island (continued)</u>						
Heber	Heber Diversion	3.5 m3/s	0.6 m3/s make-up	Nil	Not established	No
Puntledge	Puntledge Diversion	28 m3/s	Nil	5.7 m3/s Mar-Jun 8.5-14 m3/s Jun-Aug 4 m3/s Sep-Oct 2.8 m3/s Nov-Feb 21 m3/s below Browns River	Reduction in pulse floods	No
Ash	Elsie Lake Dams	10.8 m3/s	3.5 m3/s mean min. monthly in lower Ash, 0.7 m3/s min. from Elsie Lake Jun-Aug, 0.3 m3/s at other times	Nil	Not established	Yes (powerplant No (spillway)
Jordan	Elliott Dam	10.4 m3/s	Nil	Nil	Not established	No

Continued --->

Table 1 continued

River	Diversion / Dam (*1)	Licensed Diversion	Releases Required by Water Licence	DFO - B.C. Hydro Agreements	Optimum Release Schedule for Salmon Production	Released Water Availabl for Power Generation
Coastal						
Cheakamus	Cheakamus	27 m3/s	Required although specific amounts not stated	Releases from Daisy Lake to make up flows below Rubble Creek to 14 m3/s (*3)	Not established	No
Big Falls Creek	Falls River	17 m3/s	Nil	Nil	Not established	Yes

*1 Lowermost project indicated in case of sequential dams
*2 Not established by site specific studies
*3 Not accepted by B.C. Hydro

Table 2. Status of anadromous salmon habitats in rivers regulated by B.C. Hydro projects

River System	Status of Salmonid Habitats Relative to Hydro Operations	Other Impacting Factors	Potential for Improved Salmon Production Under Improved Water Management	Hydroelectric Project	Generating Capacity (MW)	Proportion of Generating Capacity (%)
<u>Fraser River System</u>						
Coquitlam River	1. Coho rearing areas restricted by summer low flows 2. Summer water temperatures too high for rearing coho and other species	1. Gravel extraction 2. Channelization 3. Urban encroachment	Increased summer discharges would likely increase coho production	Coquitlam (supplies Buntzen plants)	76.7 (Buntzen)	0.8
South Alouette River	1. Fall flows too low for migrating spawners 2. Summer water temperatures too high for rearing coho and other species 3. Flash floods impact incubating eggs and rearing fry	1. Channelization 2. Heavy siltation 3. Urban encroachment	1. Increased steady summer discharges would enhance salmonid rearing capacity 2. Periodic moderate discharges at appropriate times to flush sediments	Alouette (supplies Stave Alouette and Ruskin plants)	52.5 (Stave Falls) 105.6 (Ruskin) 8.0 (Alouette)	0.6 1.1
Stave River	1. Fry stranded by sudden water level fluctuations 2. Redds exposed by drops in water levels	Not documented	1. Stabilize flows to avoid stranding 2. Maintain adequate flows for wetting of redds	Stave Falls Ruskin	52.5 105.6	0.6 1.1
Wahleach Creek	Pink spawning channel constructed and maintained by B.C. Hydro	Sedimentation from inflows	Not applicable	Wahleach	60.0	0.6
Bridge River	1. Fall flows too low for migrating spawners 2. Mainstem flows restrict incubation and rearing 3. Summer water temperatures may be too high for mainstem rearing	1. Placer mining 2. Siltation from logging, road construction	1. Year-round releases through Terzaghi Dam would enhance all aspects of mainstem production 2. Higher releases in fall to promote spawning migrations	Bridge River La Joie Seton	428.0 22.0 42.0	4.6 0.2 0.5

Continued --->

Table 2. Continued

River System	Status of Salmonid Habitats Relative to Hydro Operations	Other Impacting Factors	Potential for Improved Salmon Production Under Improved Water Management	Hydroelectric Project	Generating Capacity (MW)	Proportion of Generating Capacity (%)
<u>Fraser River System (continued)</u>						
Seton Creek	1. Migrant delays at tailrace under certain discharge regimes 2. Migrant delays at dam under certain discharge regimes 3. Sockeye smolt mortality in powerhouse 4. Pink adult and fry impingement on screens and trashracks	None	1. Continued improvement of migrant passage by operational constraints 2. Prevent smolt access to power canal by screening or deterrents	Seton	42.0	0.5
	5. Sedimentation by annual construction and removal of temporary diversion dam in Cayoosh Creek		Construction of permanent dam with flow regulation capability			
Shuswap River	1. Fluctuating flows restrict mainstem spawning and rearing capacity 2. Heavy siltation impacts eggs and fry 3. Low flows may restrict rearing capacity 4. Peers Dam restricts spawner access to Sugar Lake	Potential water transfer to Okanagan	1. Utilize Peers Dam to stabilize mainstem flows and ensure appropriate year-round water budget 2. Remove powerplant and need for desilting 3. Consider establishing access for spawners to Sugar Lake	Shuswap Falls	5.2	0.06

Continued --->

Table 2. Continued

River System	Status of Salmonid Habitats Relative to Hydro Operations	Other Impacting Factors	Potential for Improved Salmon Production Under Improved Water Management	Hydroelectric Project	Generating Capacity (MW)	Proportion of Generating Capacity (%)
Vancouver Island						
Campbell River	1. Low discharges reduce mainstem spawnin incubation and rearing capacity 2. High discharges impact benthos, dislodge gravels and eggs 3. Fluctuations displace juveniles and benthos 4. Impoundment has restricted gravel replenishment	None	Stabilize flow regime below John Hart to within prescribed limits	John Hart Ladore Strathcona	120.0 54.0 67.5	1.3 0.6 0.7
Quinsam River	1. Late summer flows may restrict mainstem rearing 2. Late summer water temperatures may restrict mainstem rearing	Clearcut logging and associated road development	Increased summer releases may improve instream rearing capacity	Quinsam River (diverted to Campbell River system)	120.0 (John Hart) 54.0 (Ladore)	1.3 0.6
Salmon River	Existing diversion has probably had little effect on habitats in lower river	Clearcut logging and associated road development	1. Coho plantings in upper watershed would require screens to pass diversion 2. Stabilized flow regime may reduce lower river flooding incidence	Salmon River (diverted to Campbell River system)	120.0 (John Hart) 54.0 (Ladore)	1.3 0.6

Continued --->

Table 2. Continued

River System	Status of Salmonid Habitats Relative to Hydro Operations	Other Impacting Factors	Potential for Improved Salmon Production Under Improved Water Management	Hydroelectric Project	Generating Capacity (MW)	Proportion of Generating Capacity (%)
<u>Vancouver Island (continued)</u>						
Heber River	Coho spawning and rearing may be affected by flow regime below diversion	Unknown	Increased flows may enhance coho production	Heber River (diverted to Campbell River system)	120.0 (John Hart) 54.0 (Ladore) 67.5 (Strathcona)	1.3 0.6 0.7
Puntledge River	1. Delays and injuries at tailrace 2. Delays and blockage at falls 3. Smolt mortality through powerhouse 4. Loss of spawning gravels by flooding 5. Late summer water temperatures may impact spawning and rearing	None	1. Continued improvement of migrant passage by operational constraints 2. Prevent smolt access to powerhouse by screening or deterrents 3. Stabilized flow regime to reduce flooding impacts 4. Higher summer releases to reduce temperature stress	Puntledge	27.0	0.3
Ash River	Coho spawning and rearing may be affected by flow regime below Elsie Lake dams	Unknown	Increased flows may enhance coho productivity	Ash River	25.2	0.3
Jordan River	Mainstem spawning and rearing disrupted by erratic flow regime below Elliott Dam	Unknown	Stabilized flow regime might assist in restoration of salmon resources (assuming habitat replacement)	Jordan River	150.0	1.6

Continued --->

Table 2. Continued

River System	Status of Salmonid Habitats Relative to Hydro Operations	Other Impacting Factors	Potential for Improved Salmon Production Under Improved Water Management	Hydroelectric Project	Generating Capacity (MW)	Proportion of Generating Capacity (%)
<u>Coastal</u>						
Cheakamus River	1. Summer low flows may restrict mainstem rearing 2. Flash floods probably impact mainstem incubation and rearing	Deteriorating water quality due to effluent discharges	1. Increased late summer flows to enhance rearing 2. Reduced flooding incidence in lower river	Cheakamus	140.0	1.5
Big Falls Creek	Chinook and coho spawning discouraged by high current velocities in tidal pool	Not documented	Negligible	Falls River	9.6	0.1

Table 3. Recommended priorities for restoration and management of regulated salmon-bearing rivers in B.C.

Enhancement Potential		Feasibility of modifications to project and/or operating regime: High	Moderate	Low	Uncertain
	High	Cheakamus Shuswap	Puntledge Bridge		
	Moderate		Coquitlam Alouette Seton Stave Wahleach Quinsam Campbell Salmon		
	Low			Heber Falls River	
	Unknown				Ash Jordan

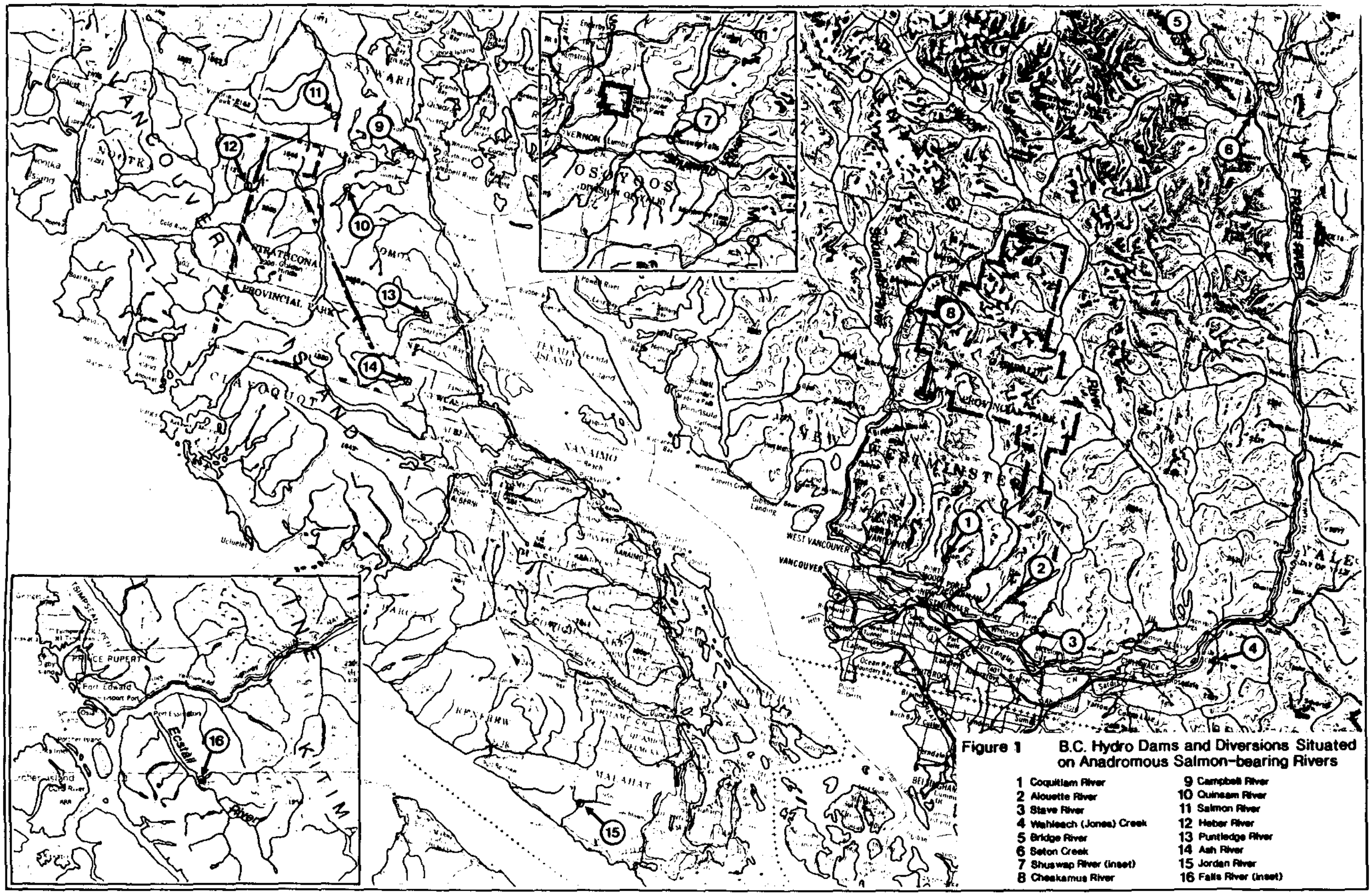


Figure 1 B.C. Hydro Dams and Diversions Situated on Anadromous Salmon-bearing Rivers

1 Coquitlam River
2 Alouette River
3 Stave River
4 Wahleach (Jones) Creek
5 Bridge River
6 Seton Creek
7 Shuswap River (inset)
8 Cheakamus River
9 Campbell River
10 Quinsam River
11 Salmon River
12 Heber River
13 Puntledge River
14 Ash River
15 Jordan River
16 Falls River (inset)

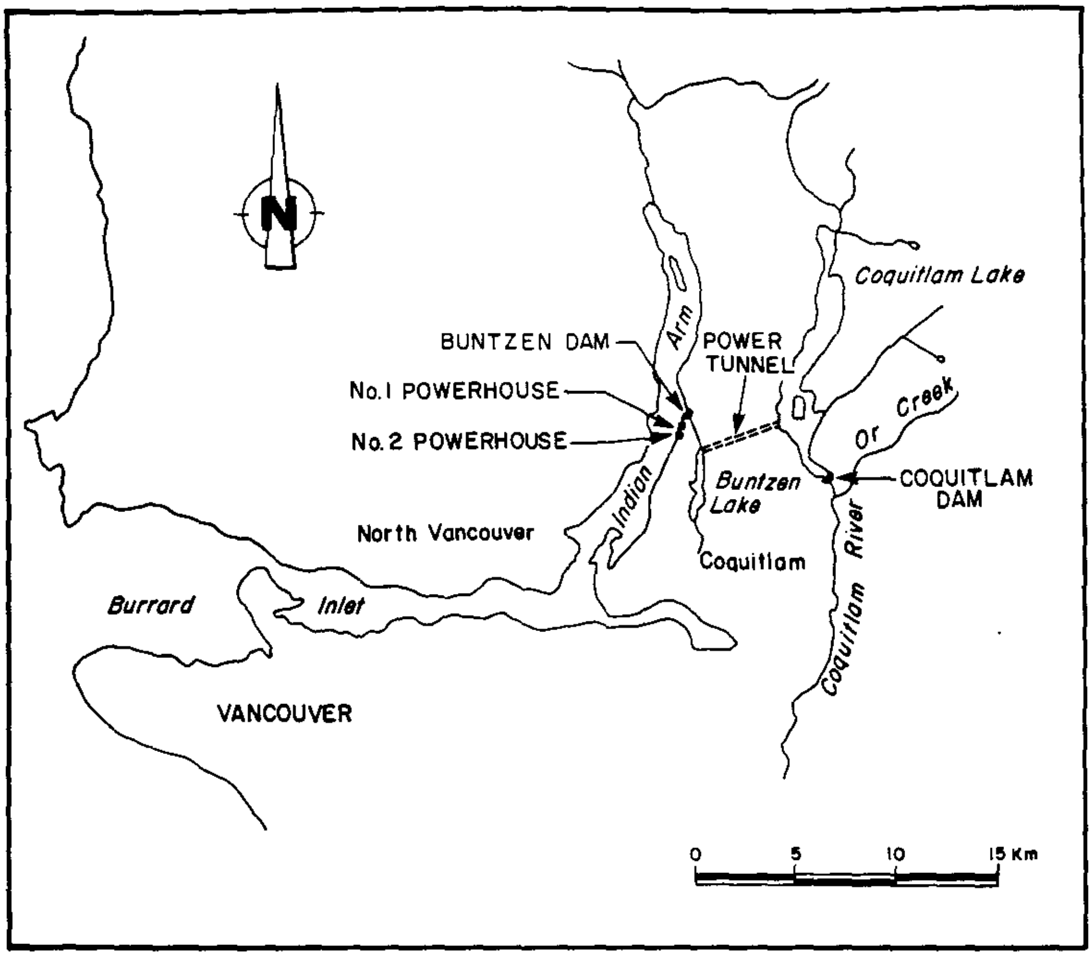


Figure 2. **Location of the Coquitlam hydroelectric development.**

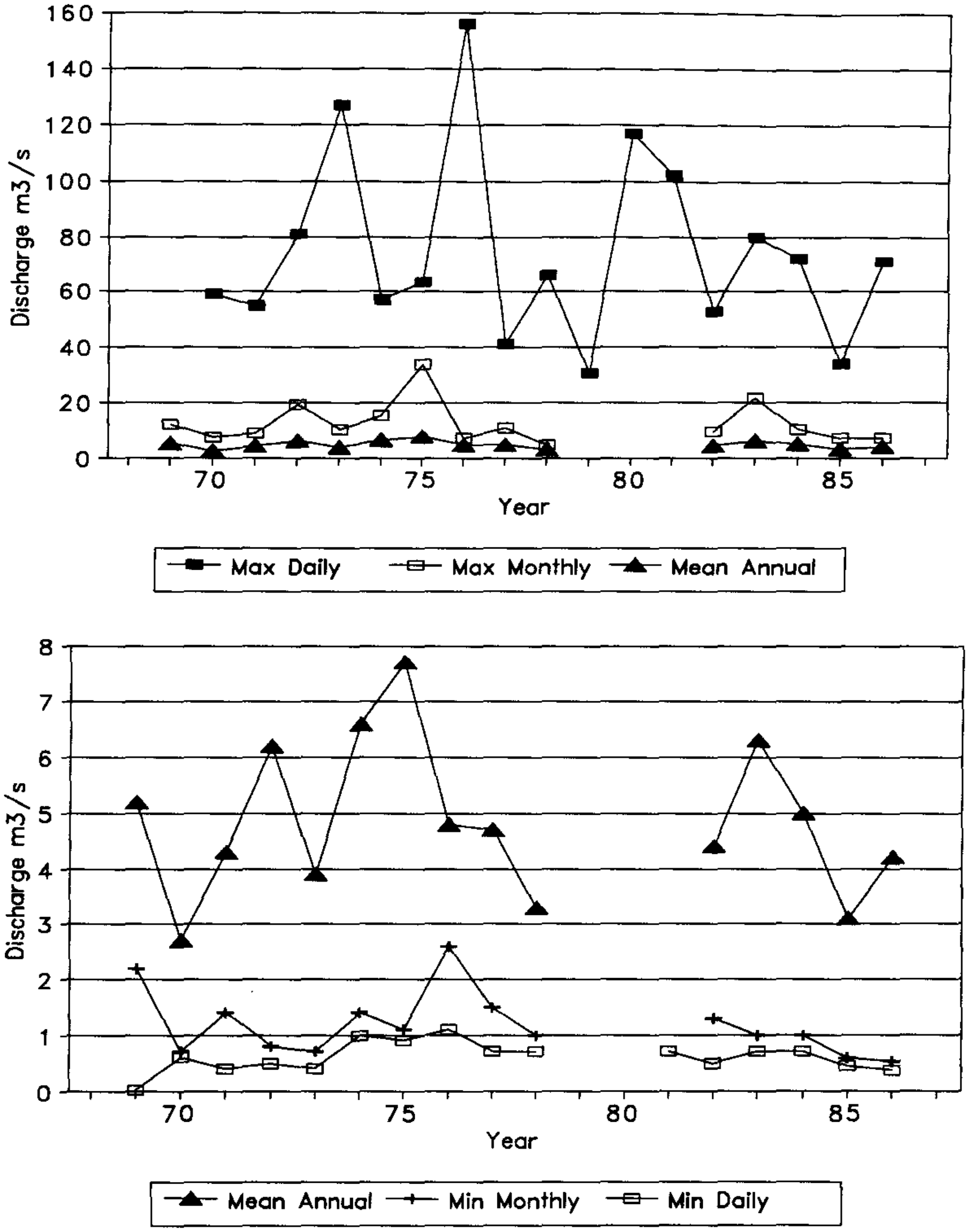


Figure 3. Post-impoundment annual flows in the Coquitlam River. Data from Inland Waters Directorate (1988).

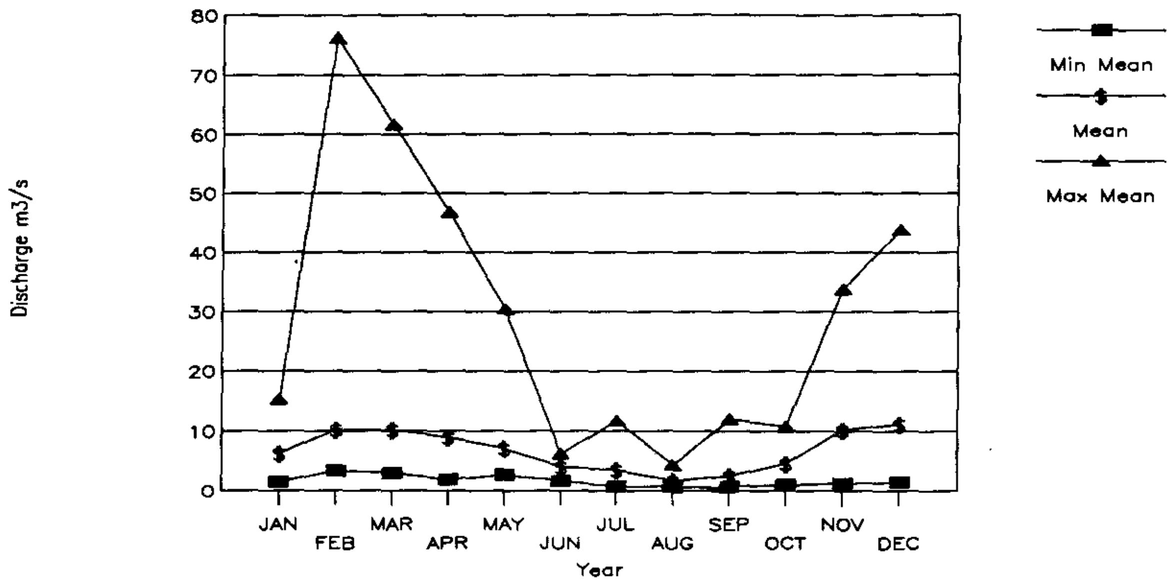
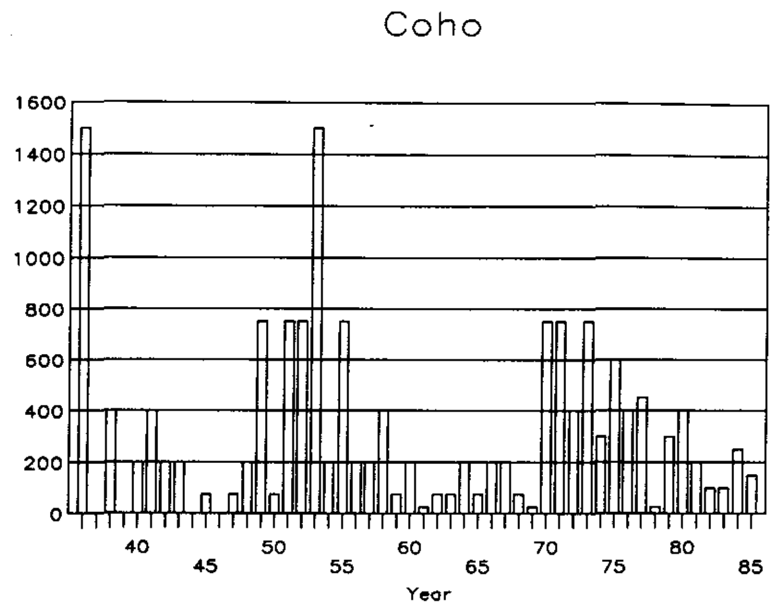


Figure 4. Post-impoundment monthly flows in the Coquitlam River. Data from Inland Waters Directorate (1988).



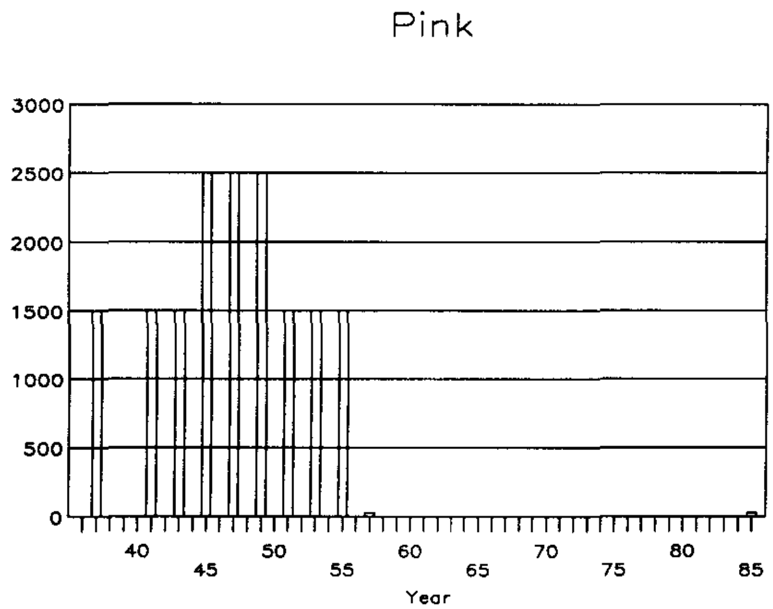
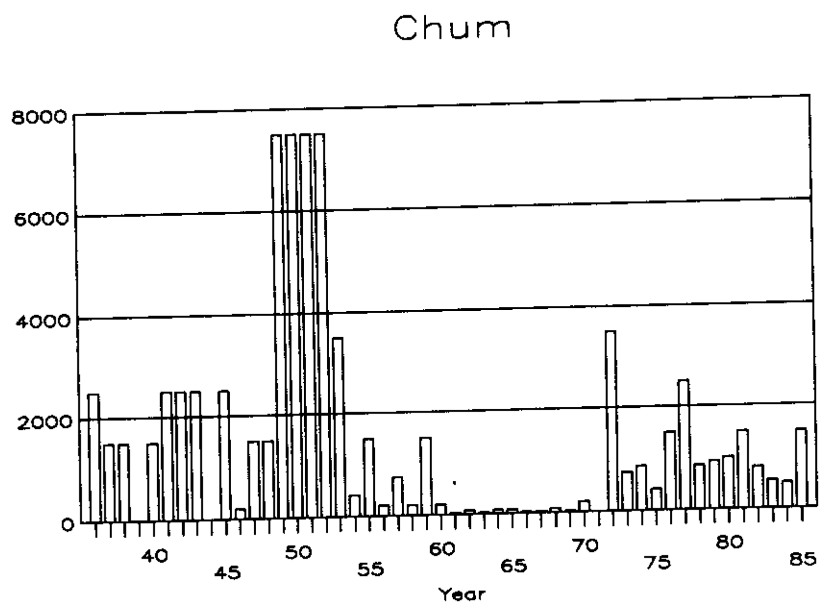


Figure 5. **Salmon escapements to the Coquitlam River. Data from Farwell et al. (1987) and DFO escapement records.**



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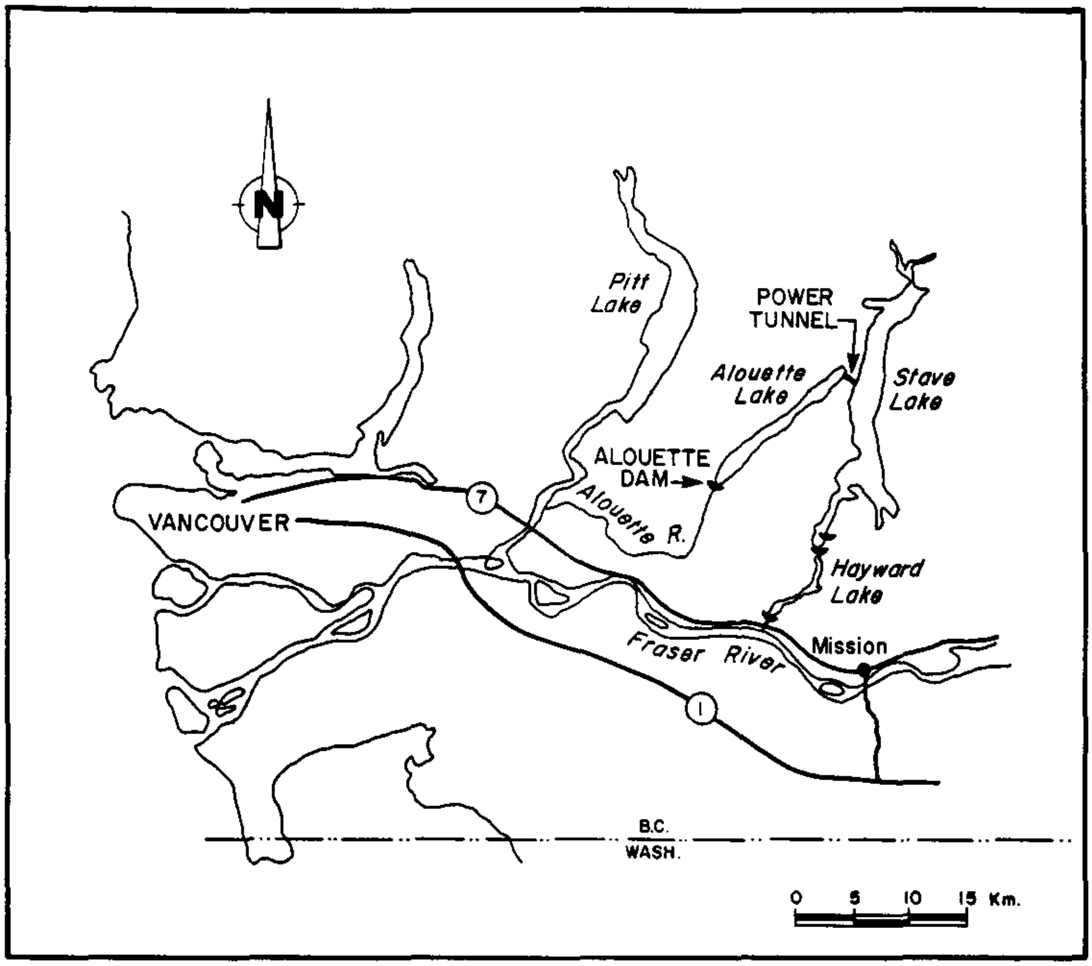


Figure 6. Location of the Alouette hydroelectric development.

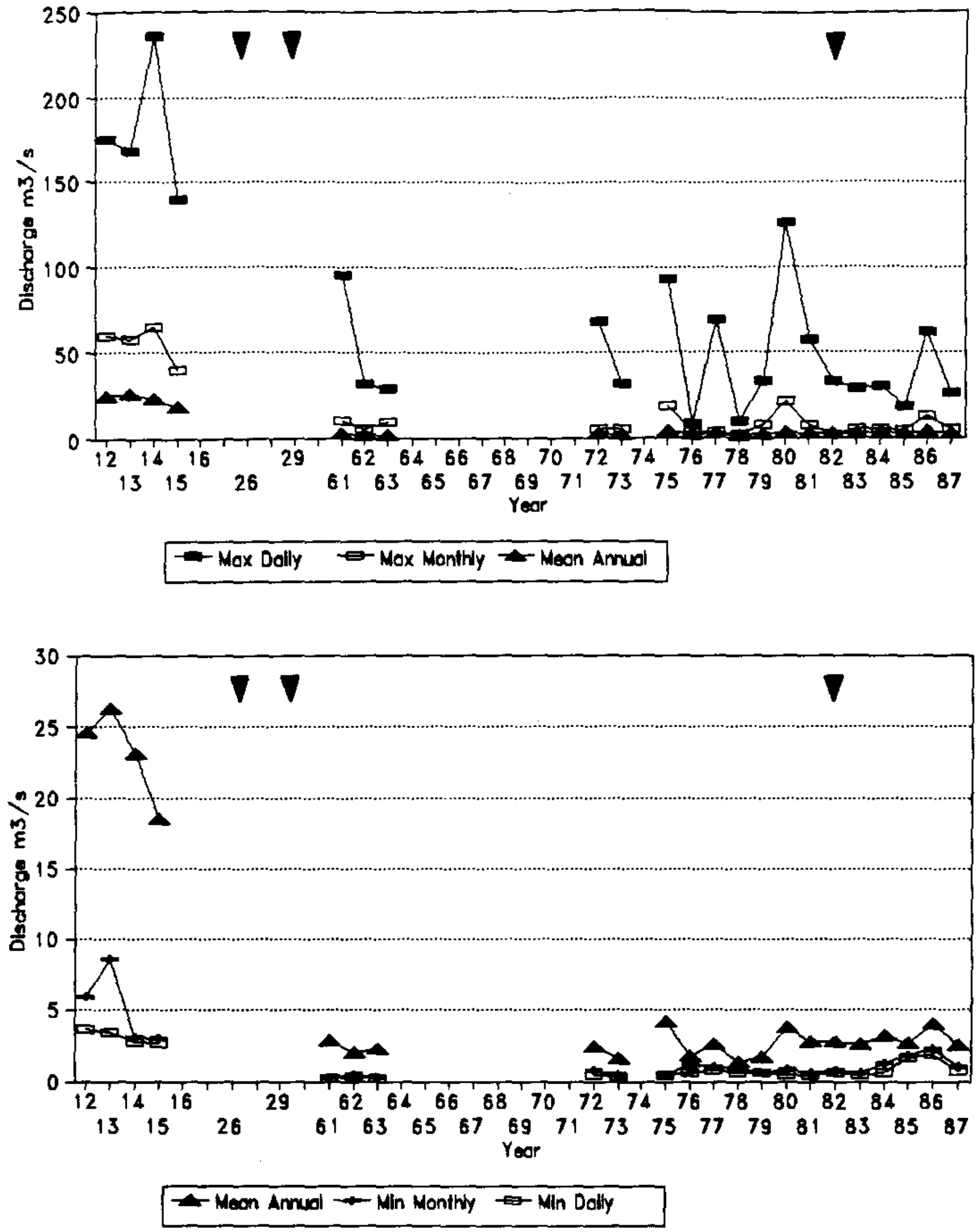
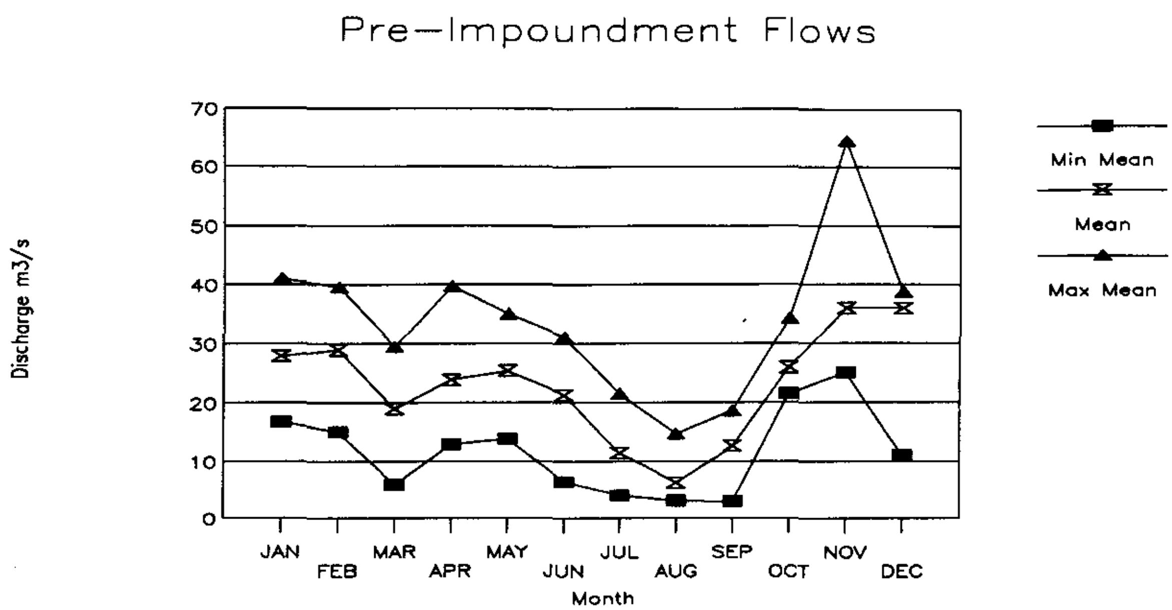


Figure 7. Pre- and post-impoundment annual flows in the South Alouette River. Arrows indicate initiation and subsequent redevelopment. Data from Inland Waters Directorate (1988).



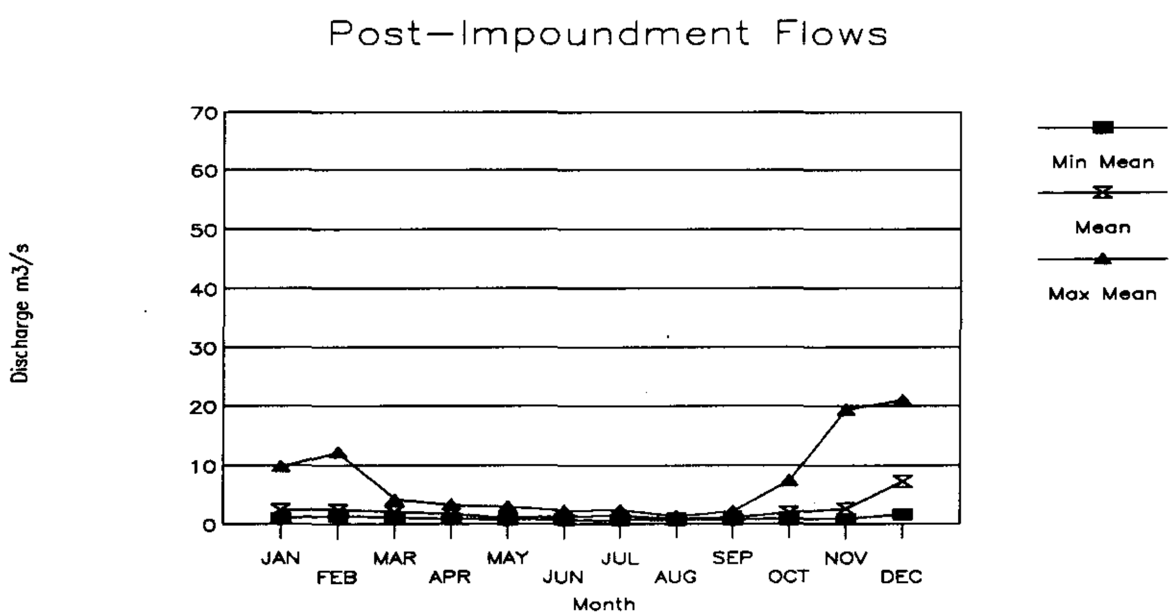
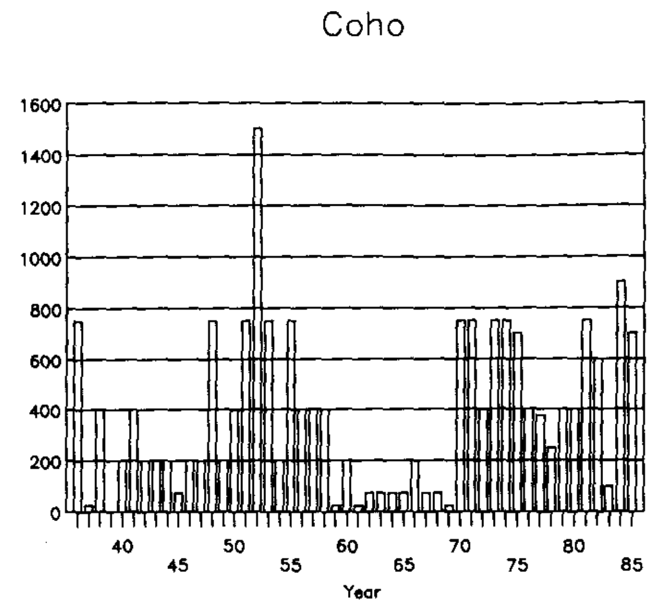


Figure 8. **Pre- and post-impoundment monthly flows in the South Alouette River. Data from Inland Waters Directorate (1988).**



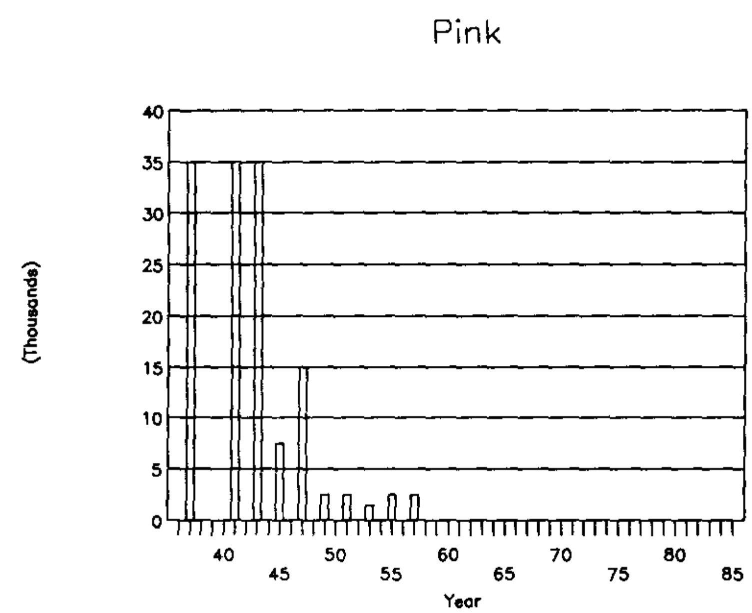
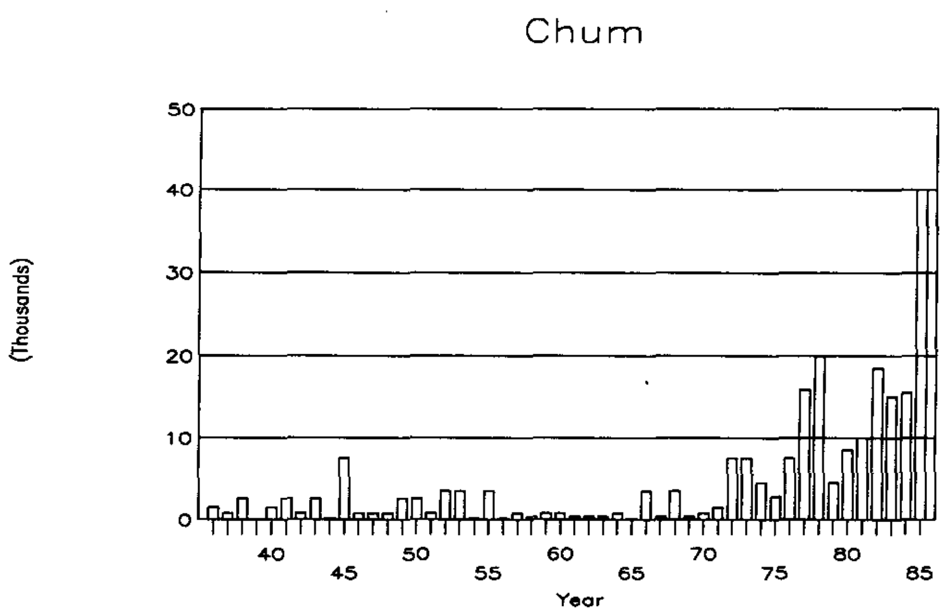


Figure 9. **Salmon escapements to the South Alouette River. Data from Farwell et al. (1987) and DFO escapement records.**



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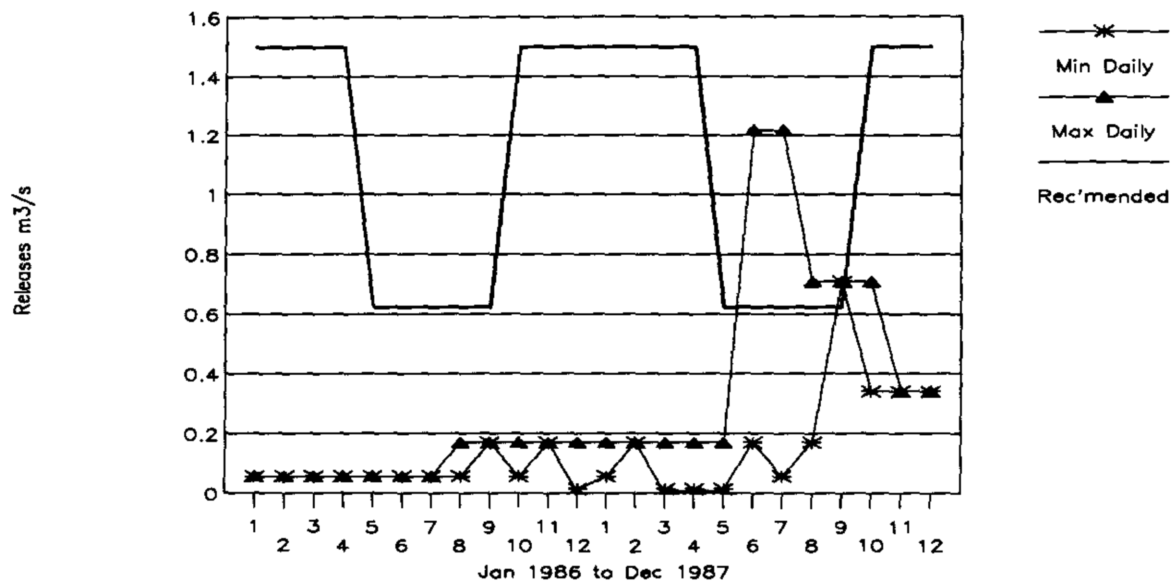


Figure 10. **Flow releases to South Alouette River through Alouette Dam (low level outlet), 1986 - 1987. Data from B.C. Hydro, Operations Control Department.**

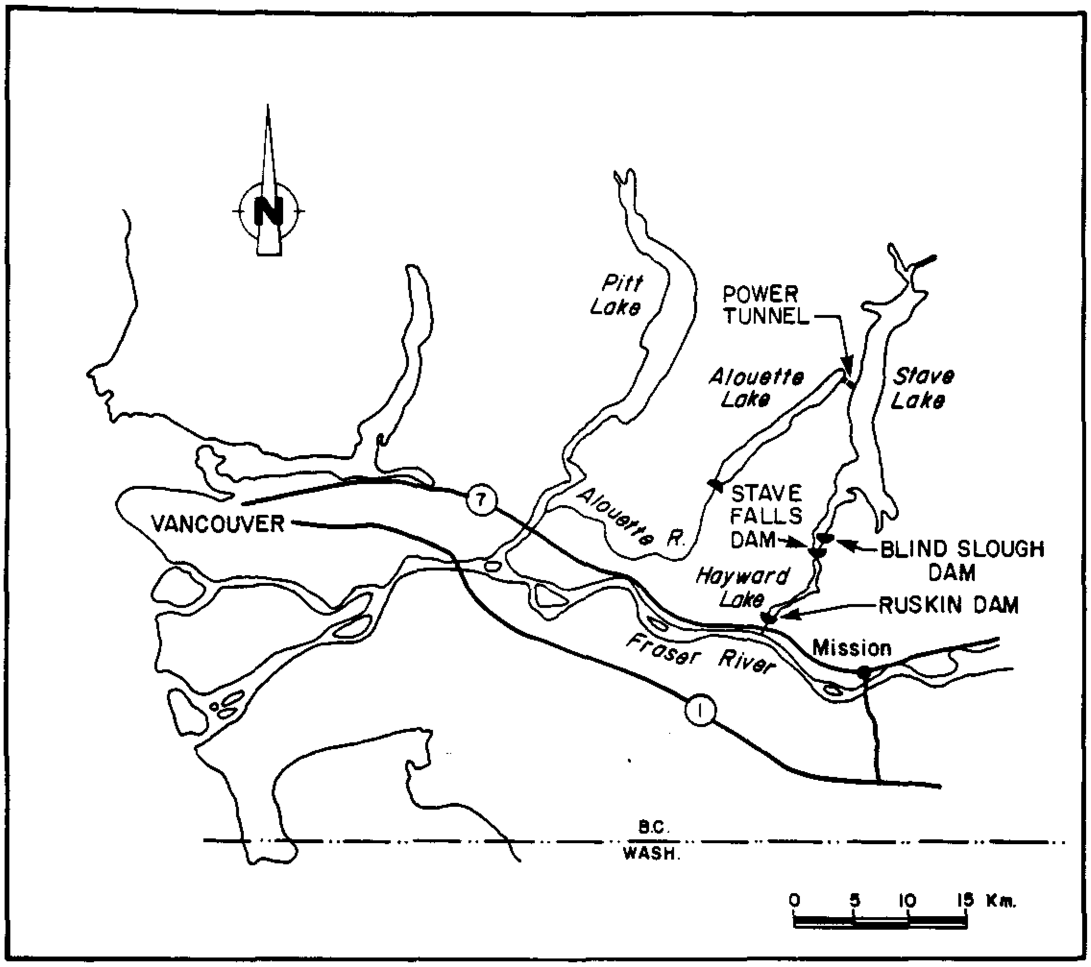


Figure 11. Location of the Stave and Ruskin hydroelectric developments.

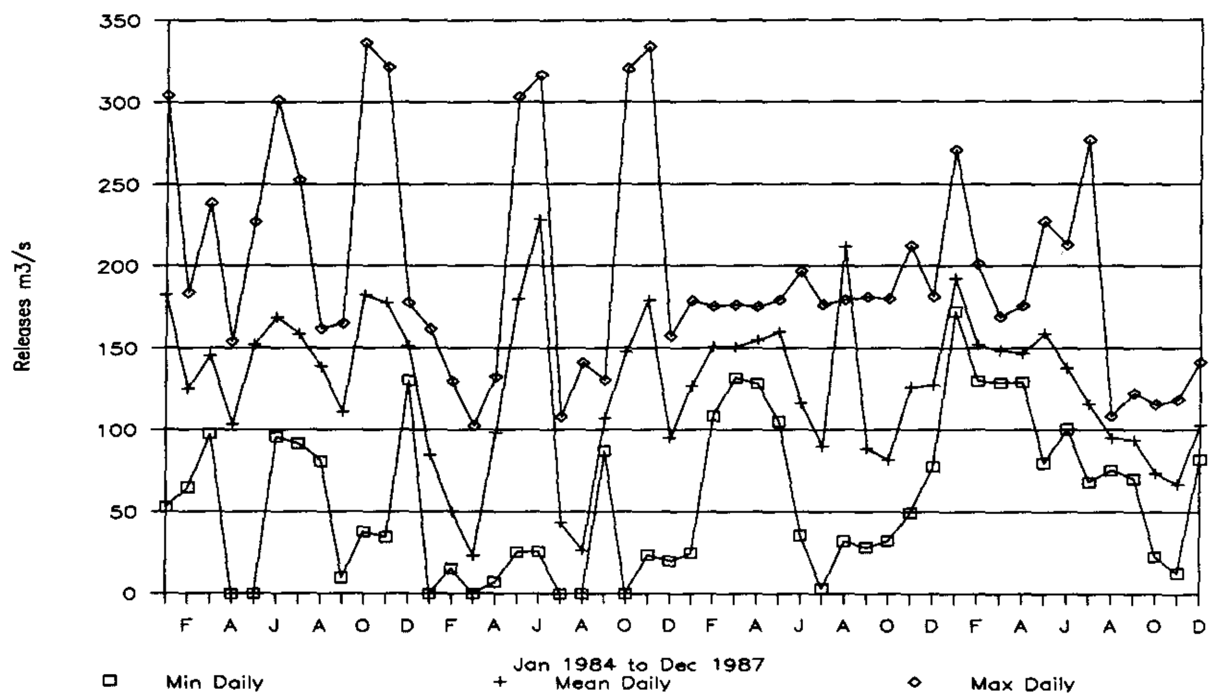


Figure 12. **Discharges through power turbines at Ruskin Dam, 1984 - 1987. No spills occurred during this period. Data from B.C. Hydro, Operations Control Department.**

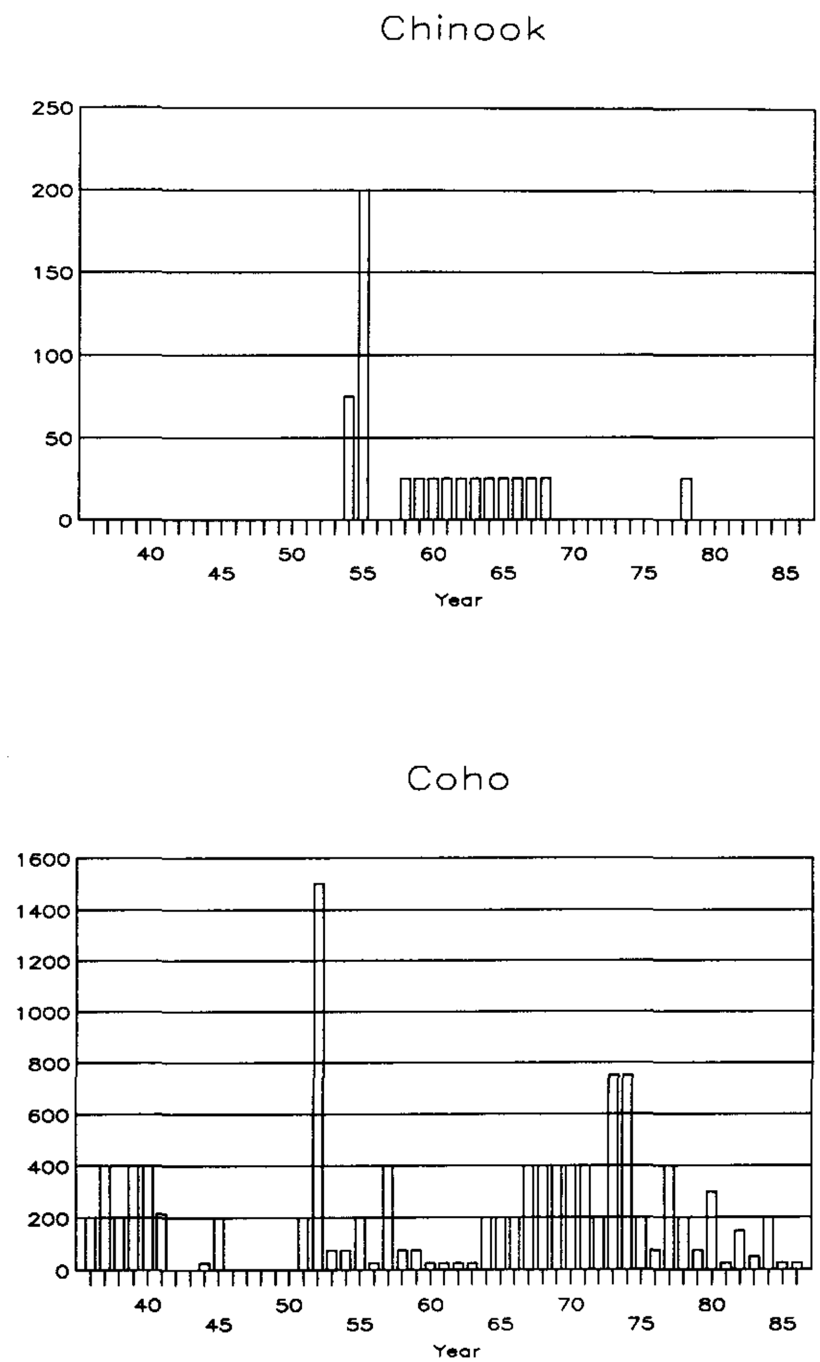
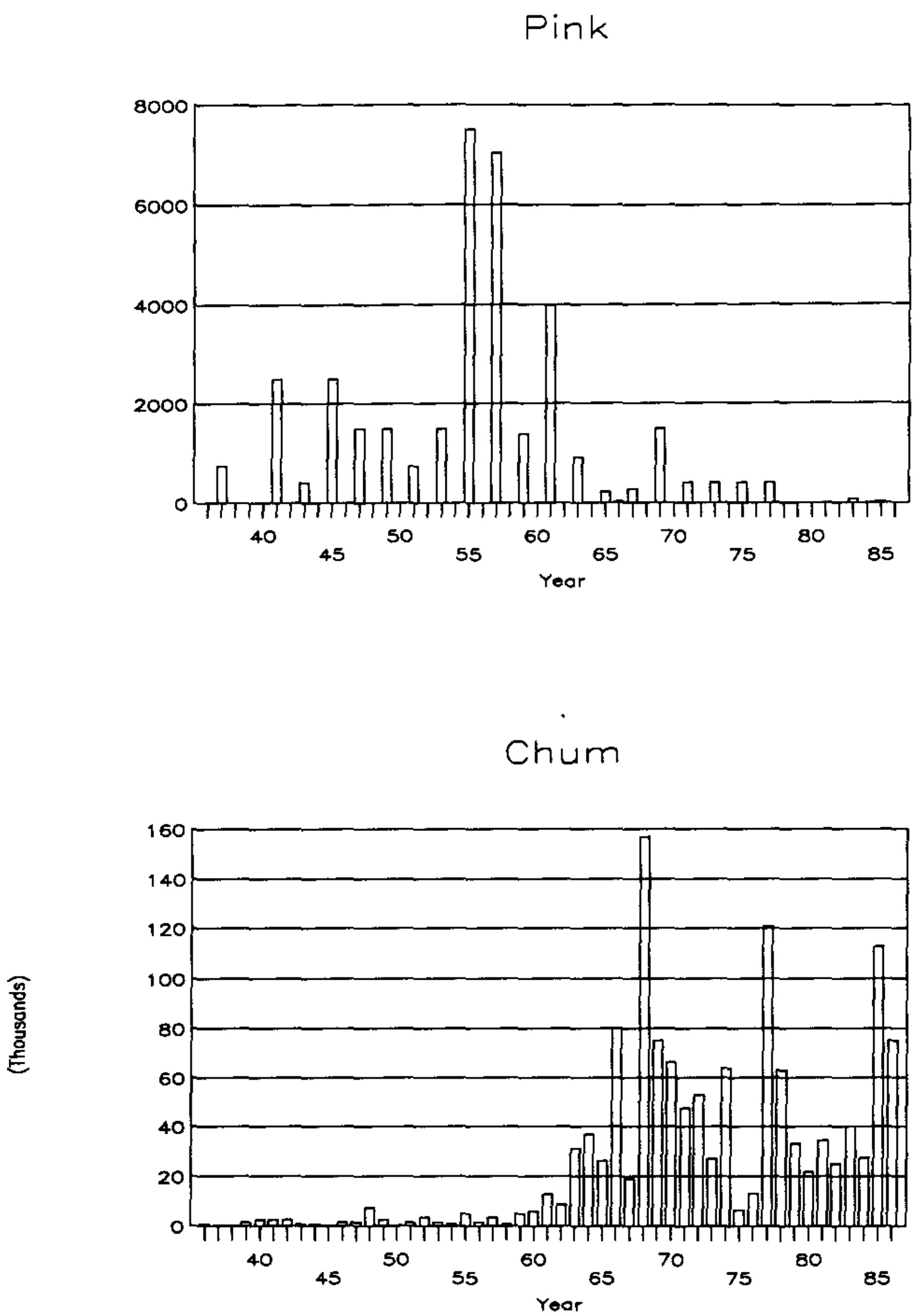


Figure 13. **Salmon escapements to the Stave River. Data from Farwell et al. (1987) and DFO escapement records.**



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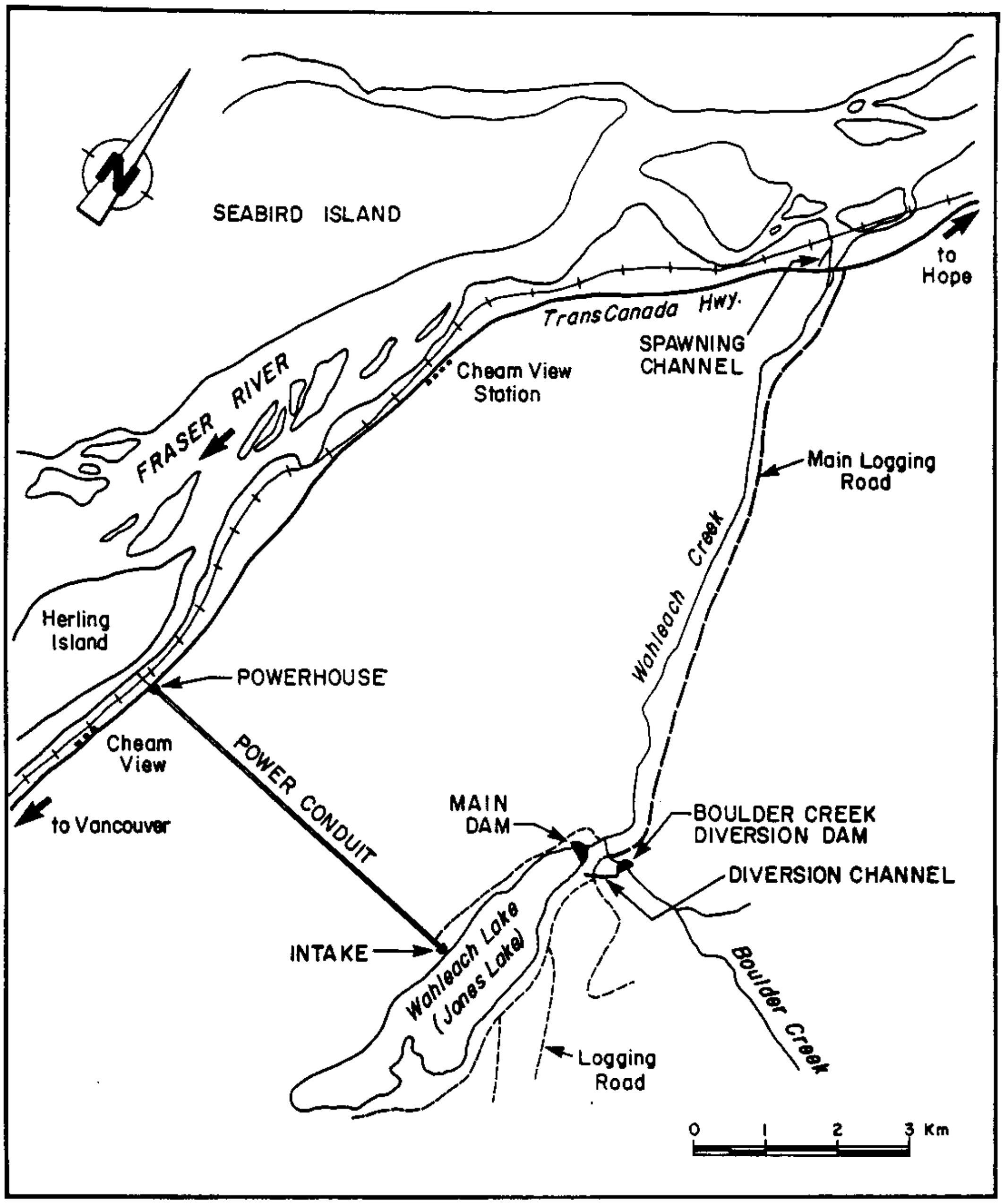


Figure 14. Location of the Wahleach hydroelectric development.

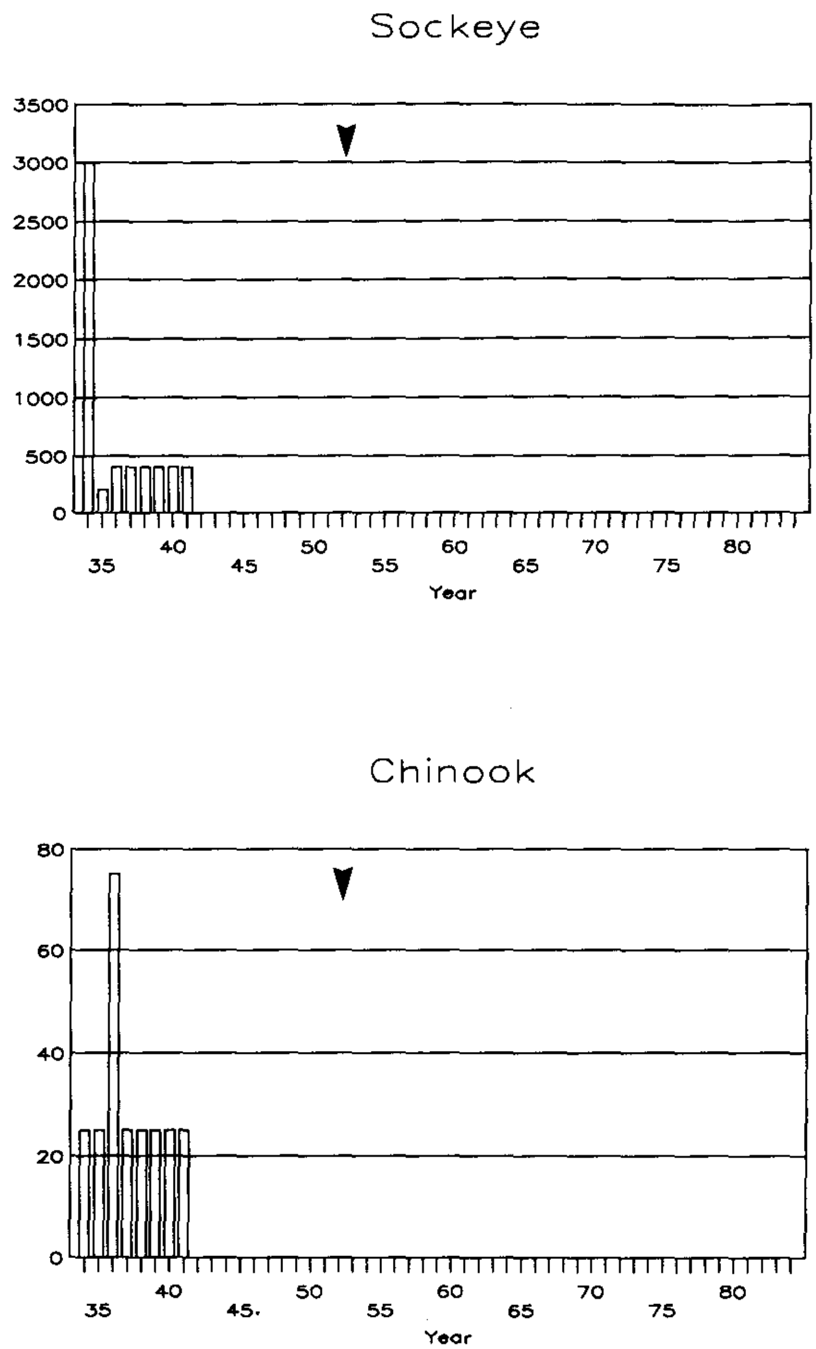
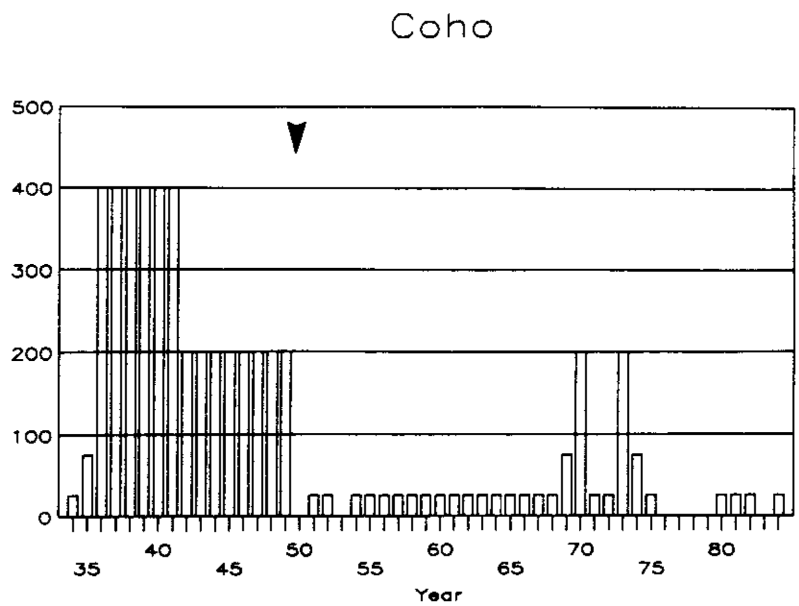
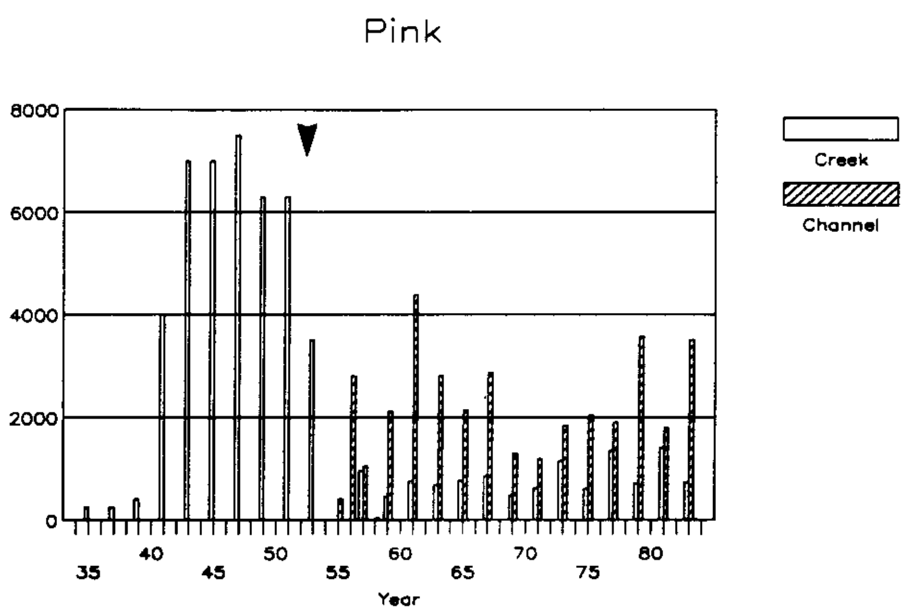


Figure 15. **Salmon escapements to Wahleach Creek and spawning channel. Arrows indicate commencement of regulated regime. Data from DFO escapement records.**





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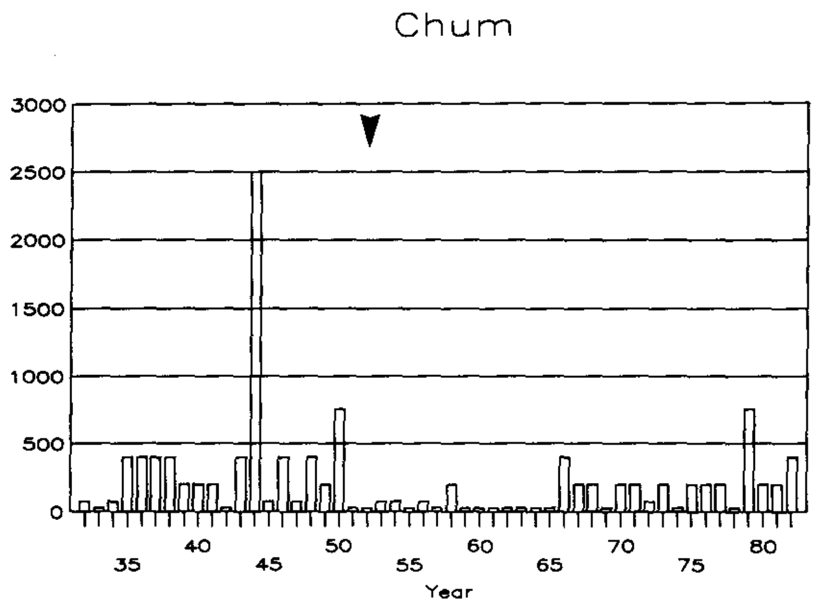

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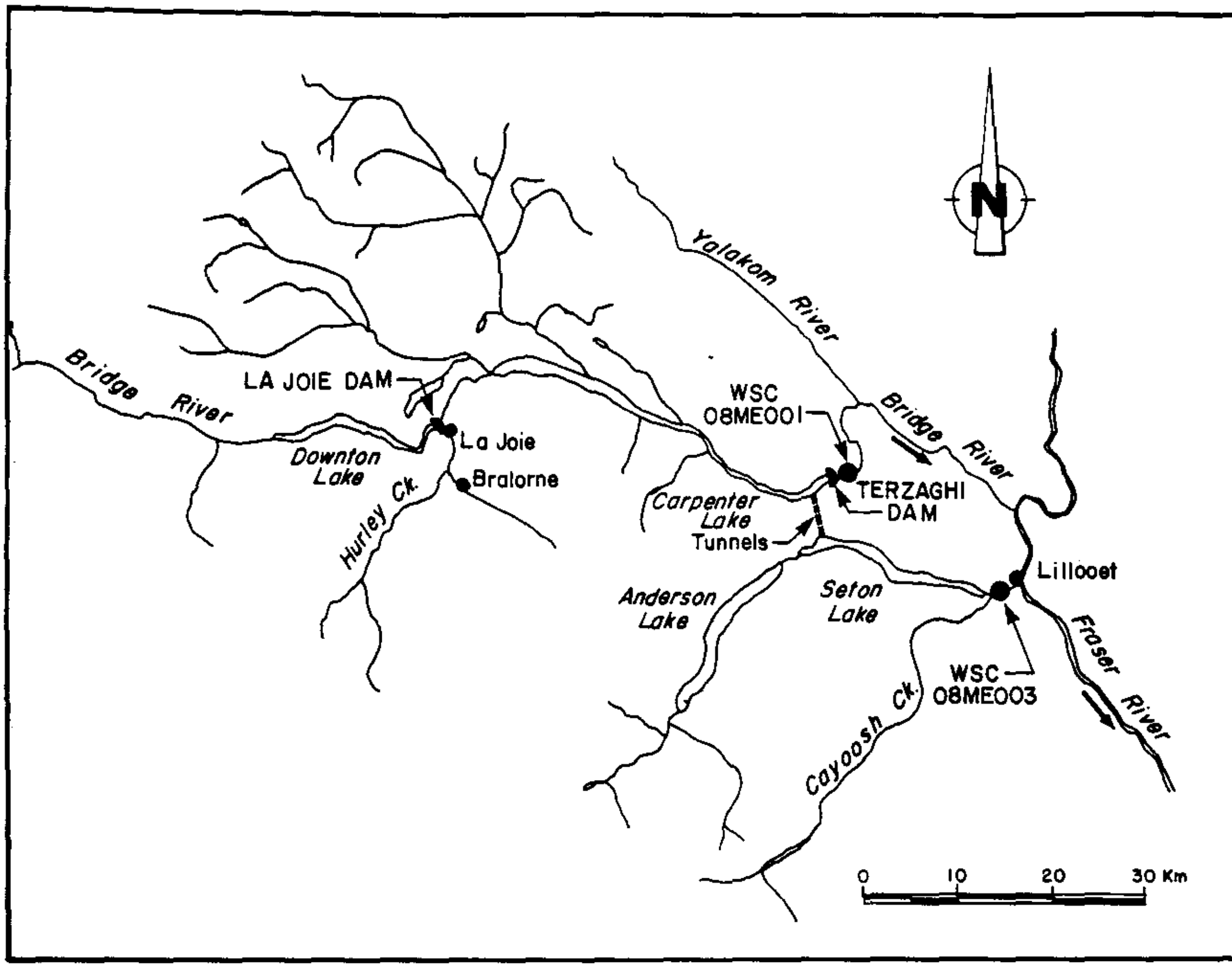


Figure 16. Location of the Bridge River hydroelectric development.

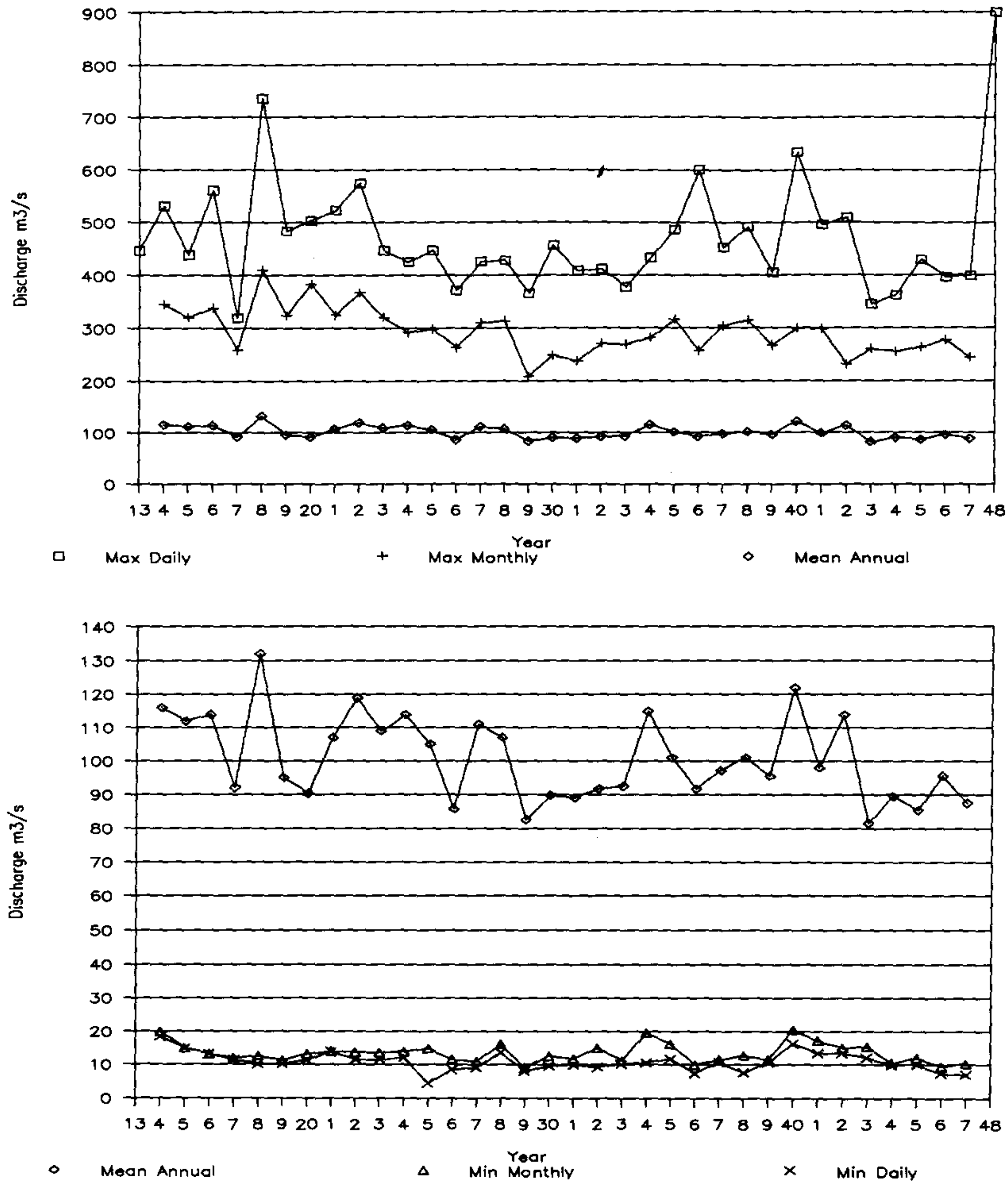


Figure 17. Pre-impoundment annual flows in the Bridge River. Data from Inland Waters Directorate (1988).

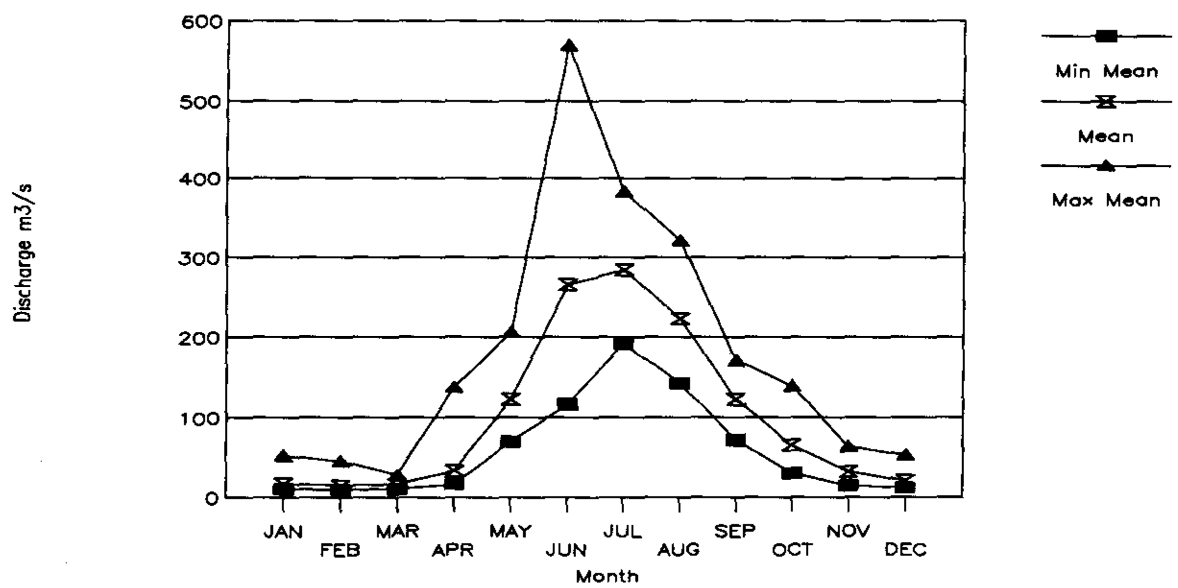
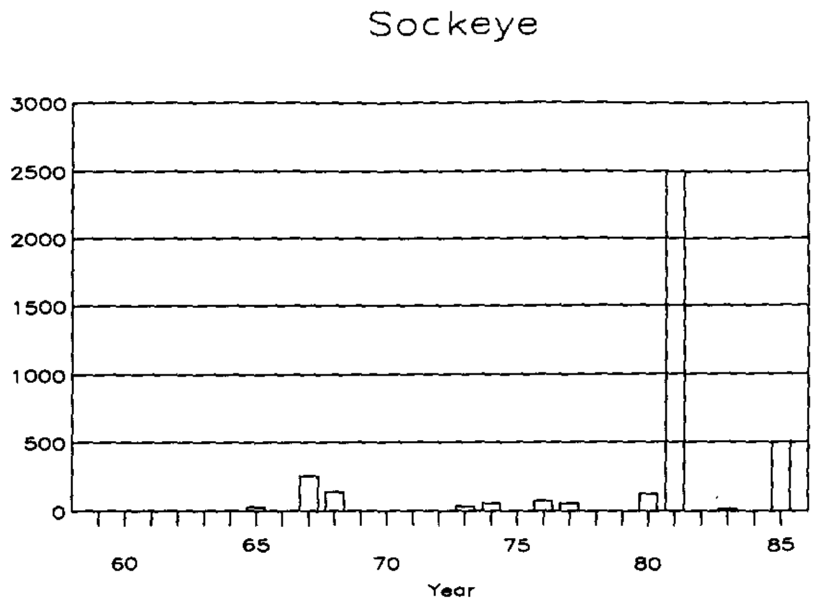


Figure 18. Pre-impoundment monthly flows in the Bridge River. Data from Inland Waters Directorate (1988).



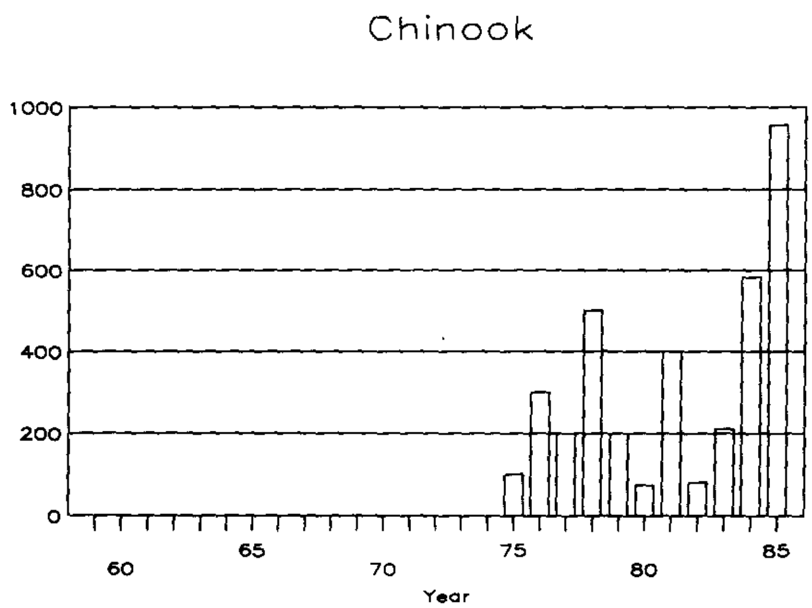
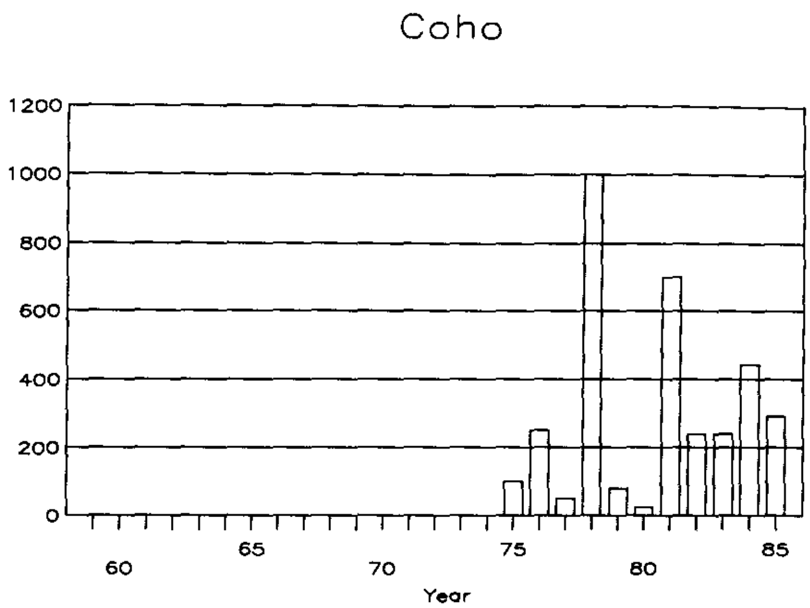
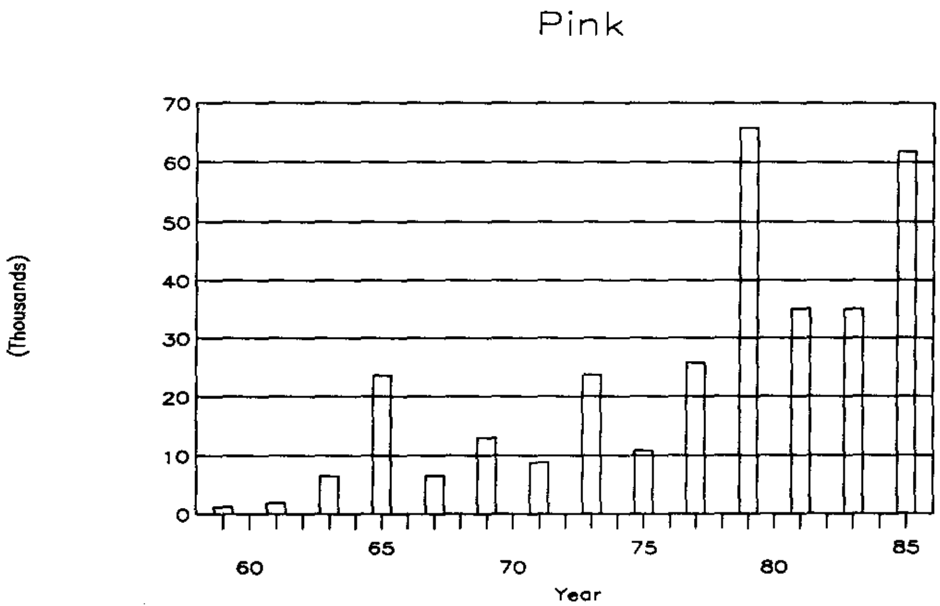


Figure 19. **Salmon escapements to the Bridge River. Data from Farwell et al. (1987) and DFO escapement records.**





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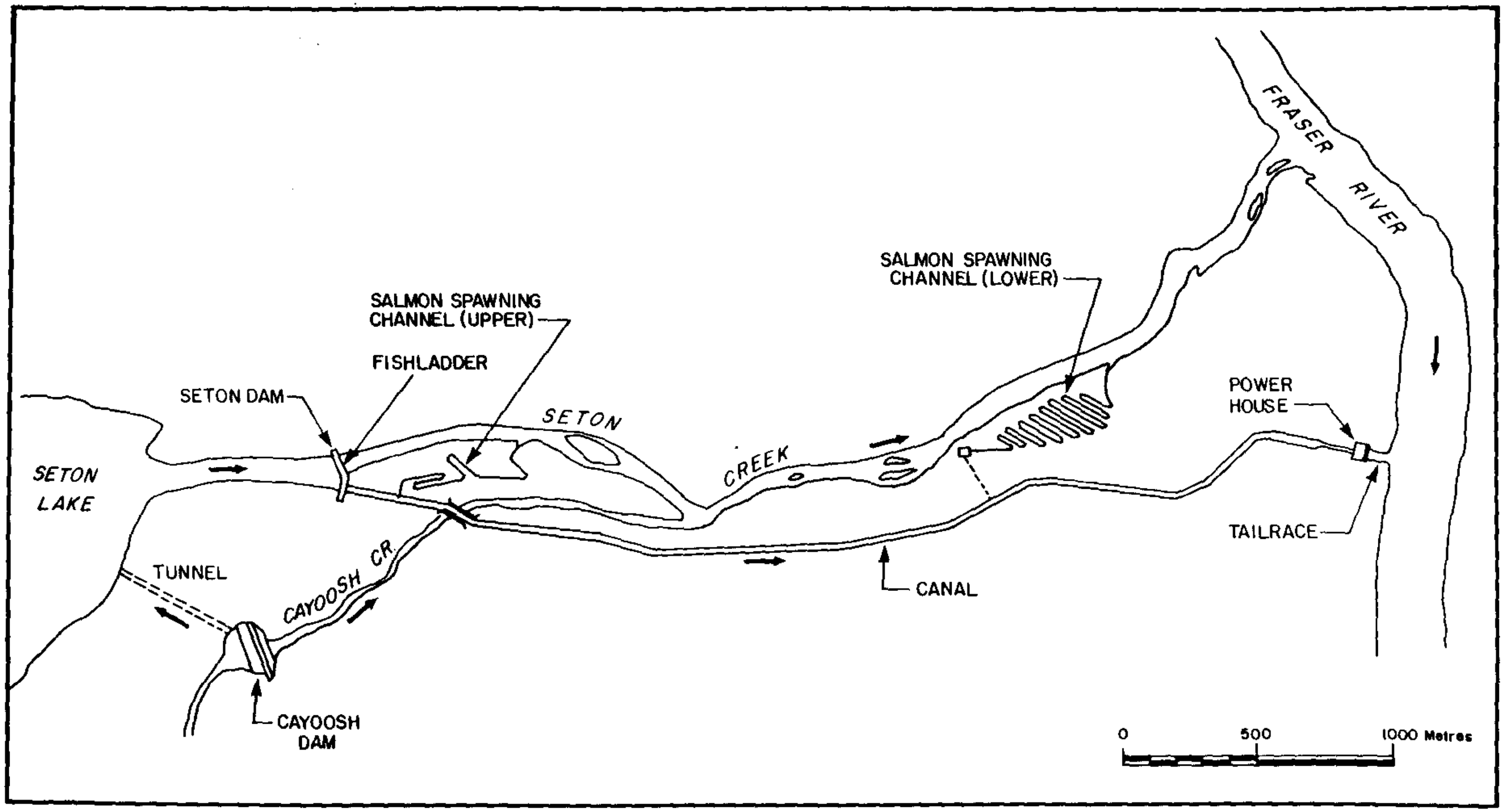


Figure 20. Location of the Seton hydroelectric development.

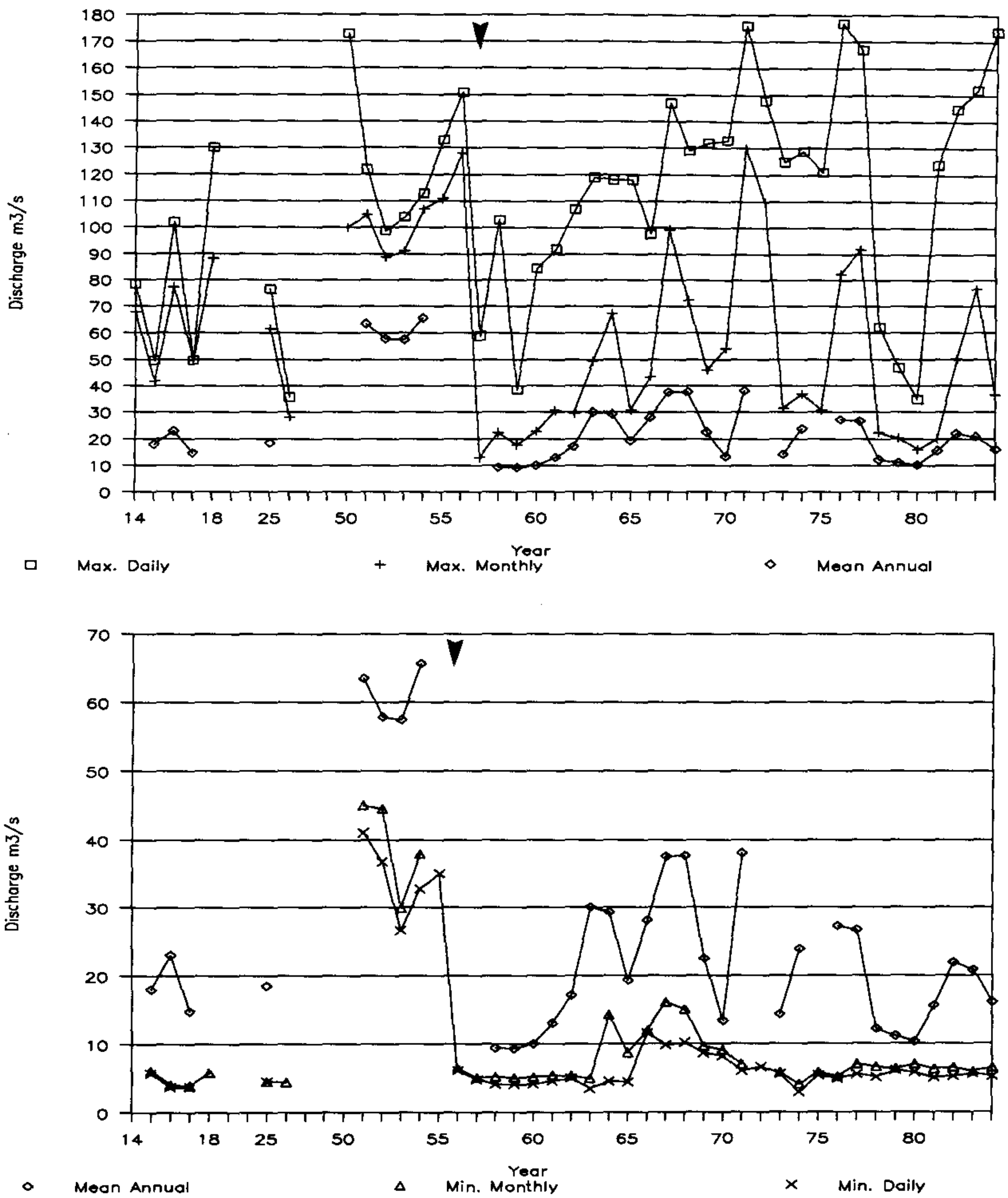
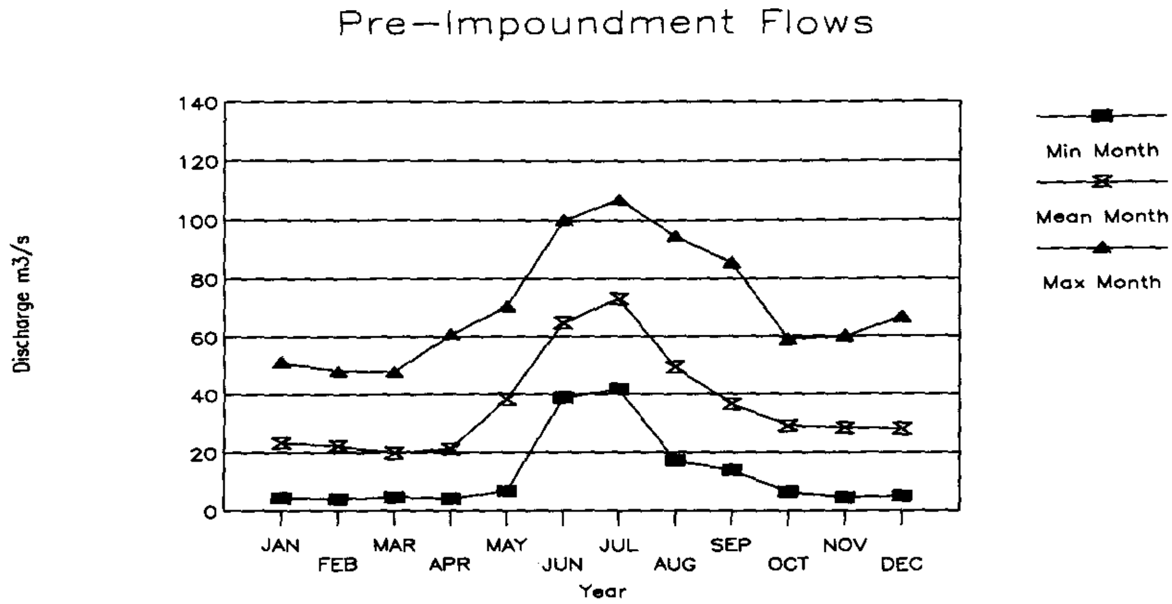


Figure 21. Pre- and post-impoundment annual flows in Seton Creek. Arrow indicates commencement of regulated regime. Data from Inland Waters Directorate (1988).



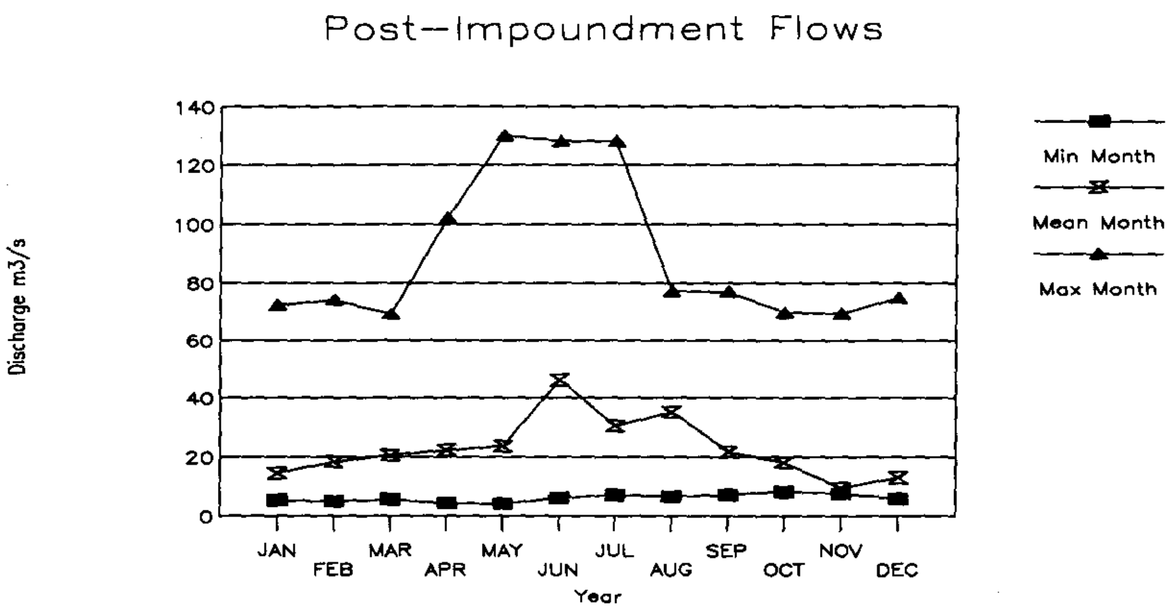


Figure 22. **Pre- and post-impoundment monthly flows in Seton Creek. Data from Inland Waters Directorate (1988).**

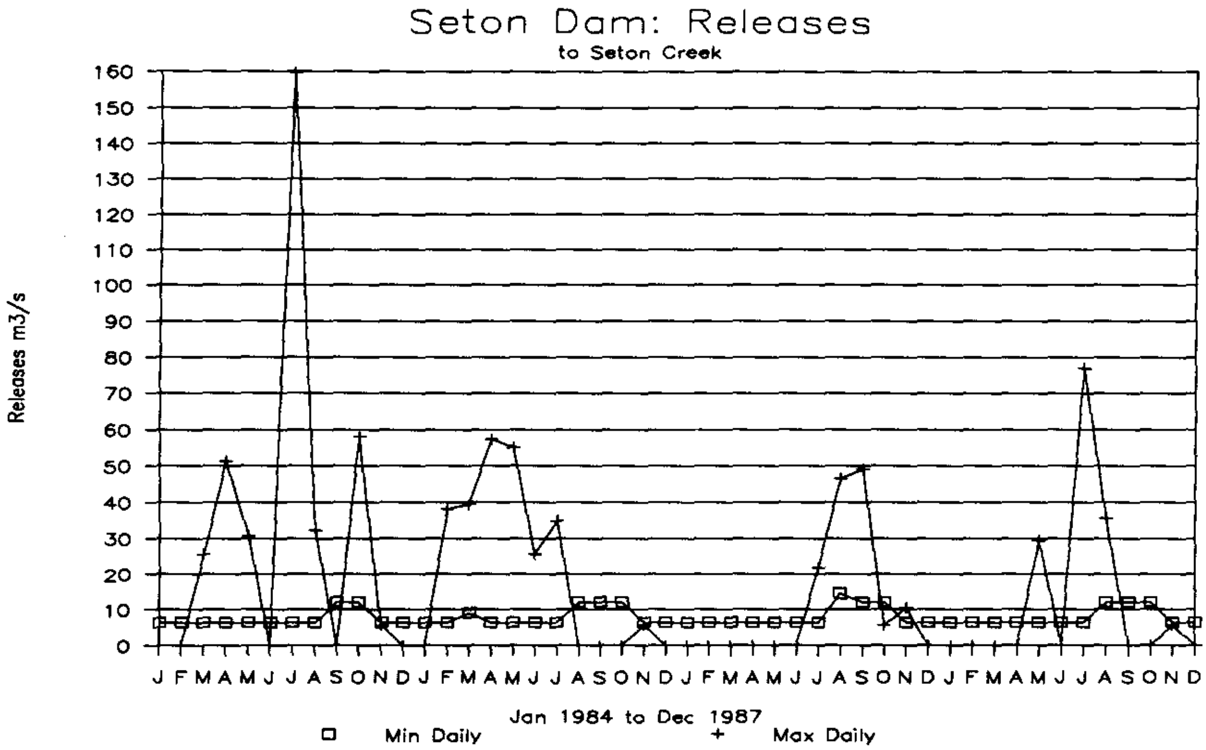


Figure 23. **Water releases through Seton Dam (all outlets) 1984 - 1987. Data from B.C. Hydro, Operations Control Department.**

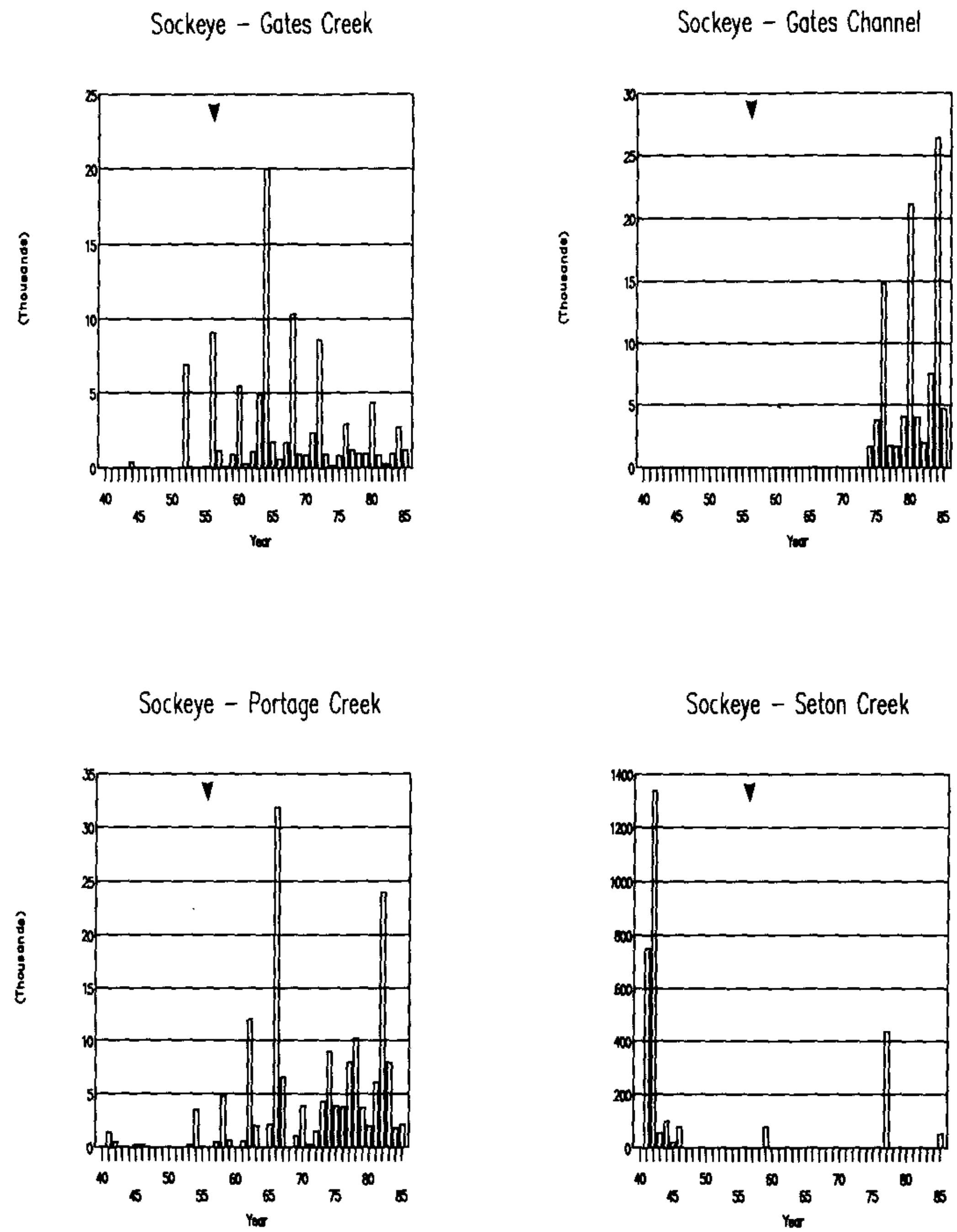
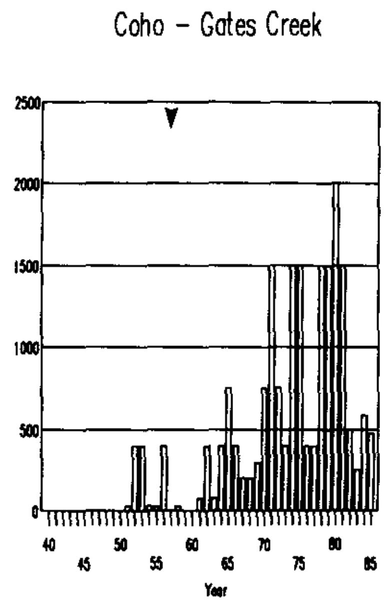
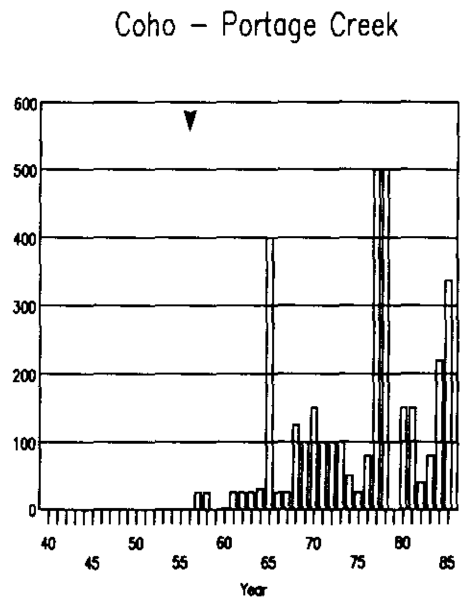
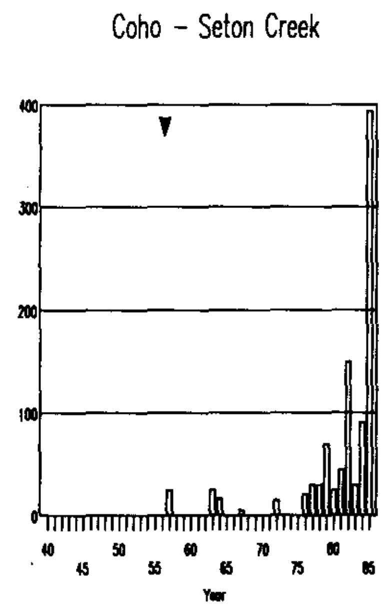


Figure 24. Salmon escapements to Seton Creek and to Gates' and Portage creek systems via Seton Creek. Arrows indicate commencement of regulated flow regime at Seton Creek. Data from Farwell et al. (1987) and DFO escapement records.







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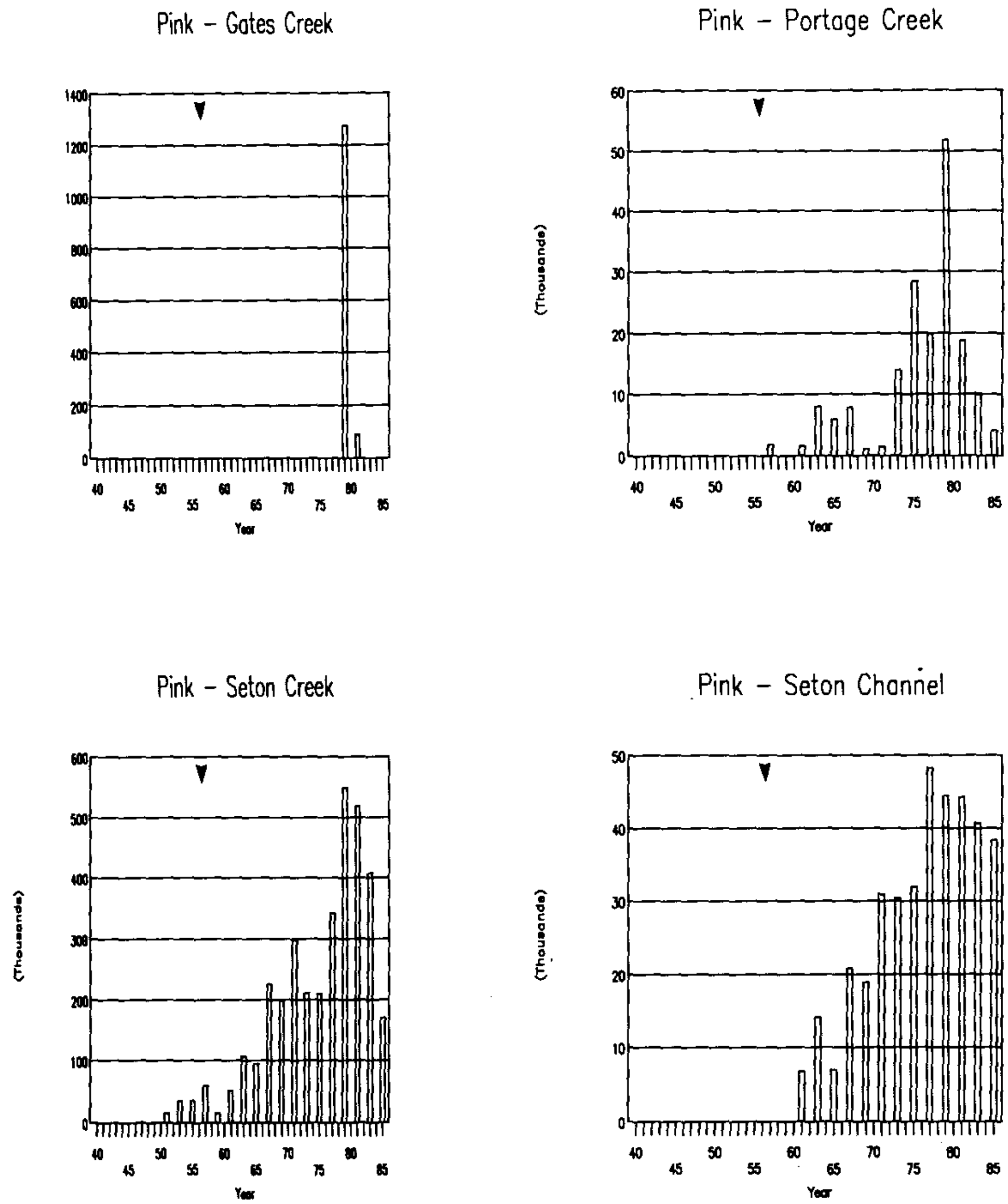

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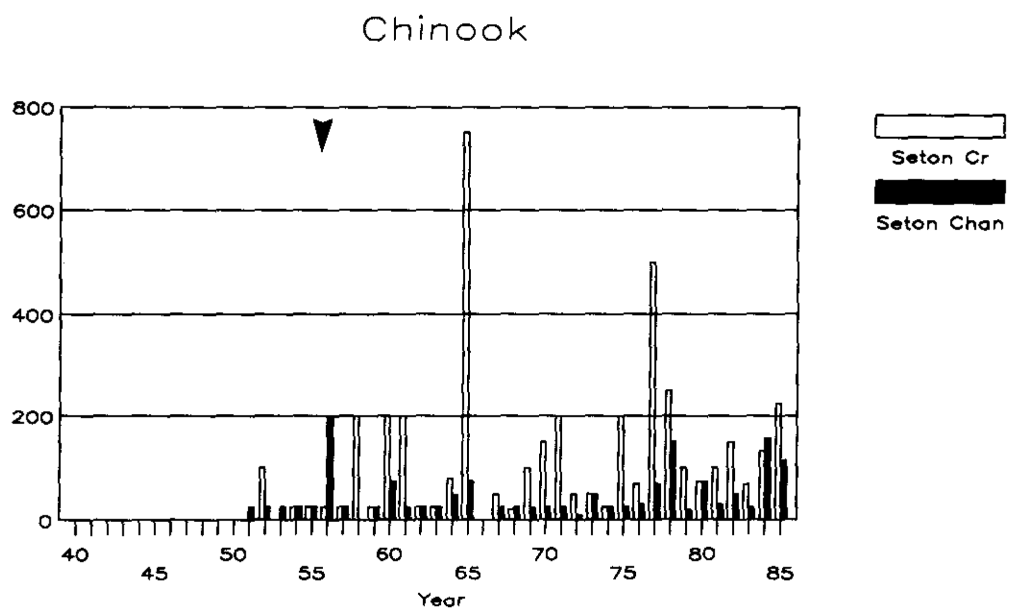

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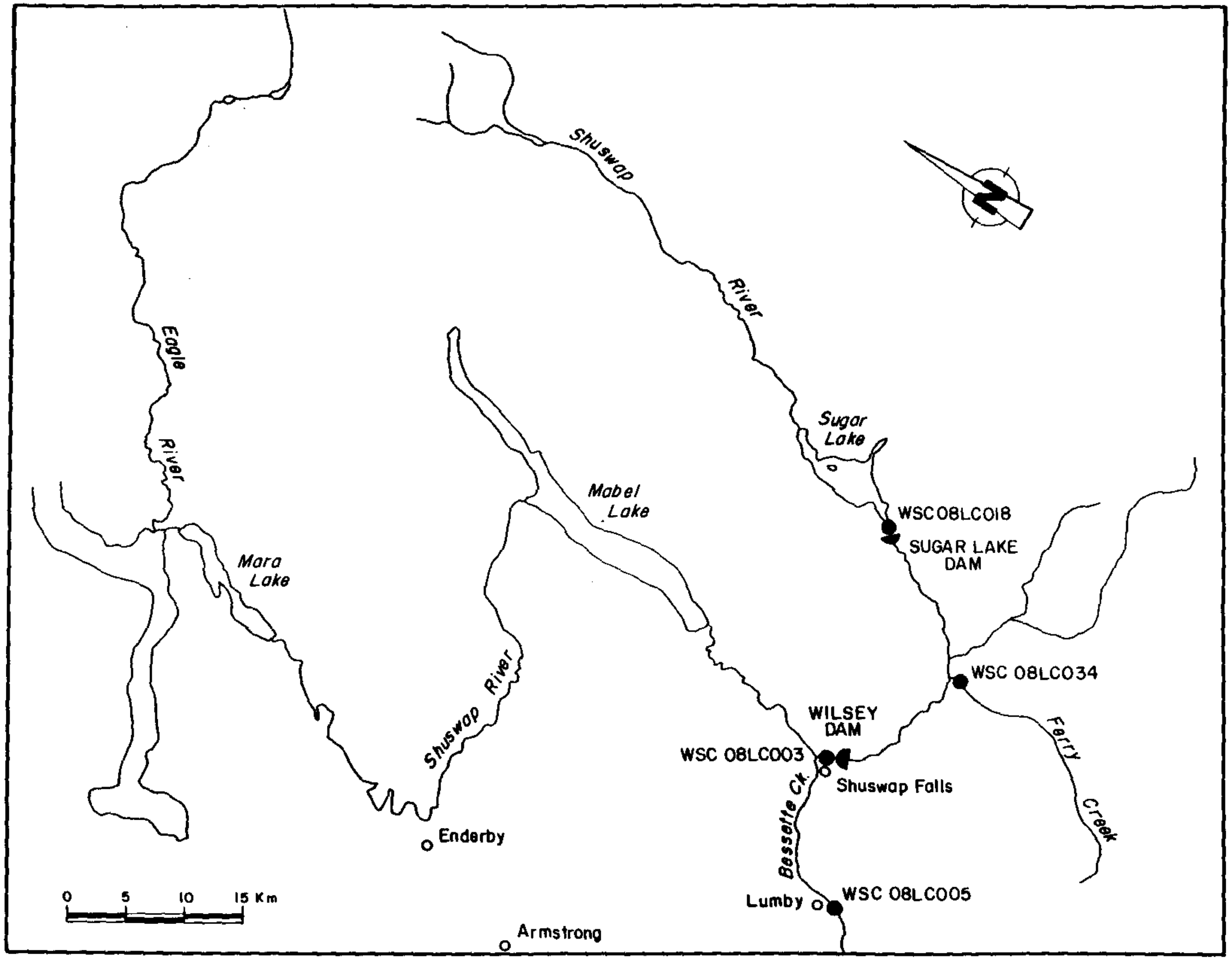
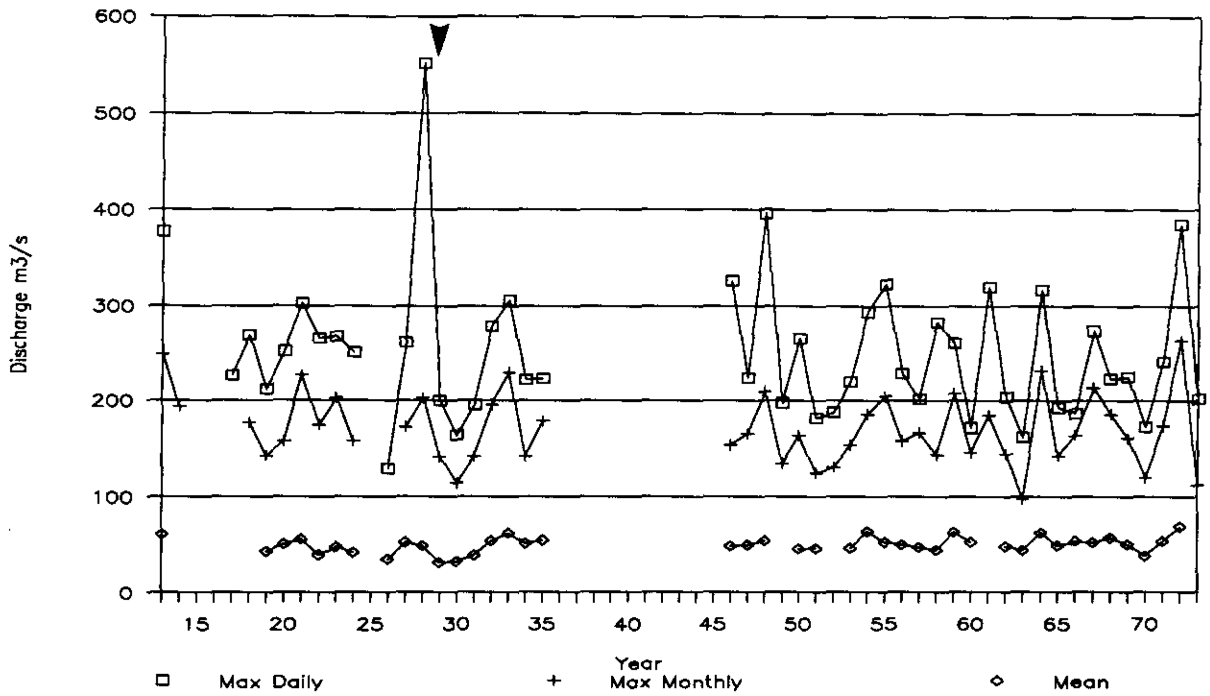


Figure 25. Location of the Shuswap hydroelectric development.



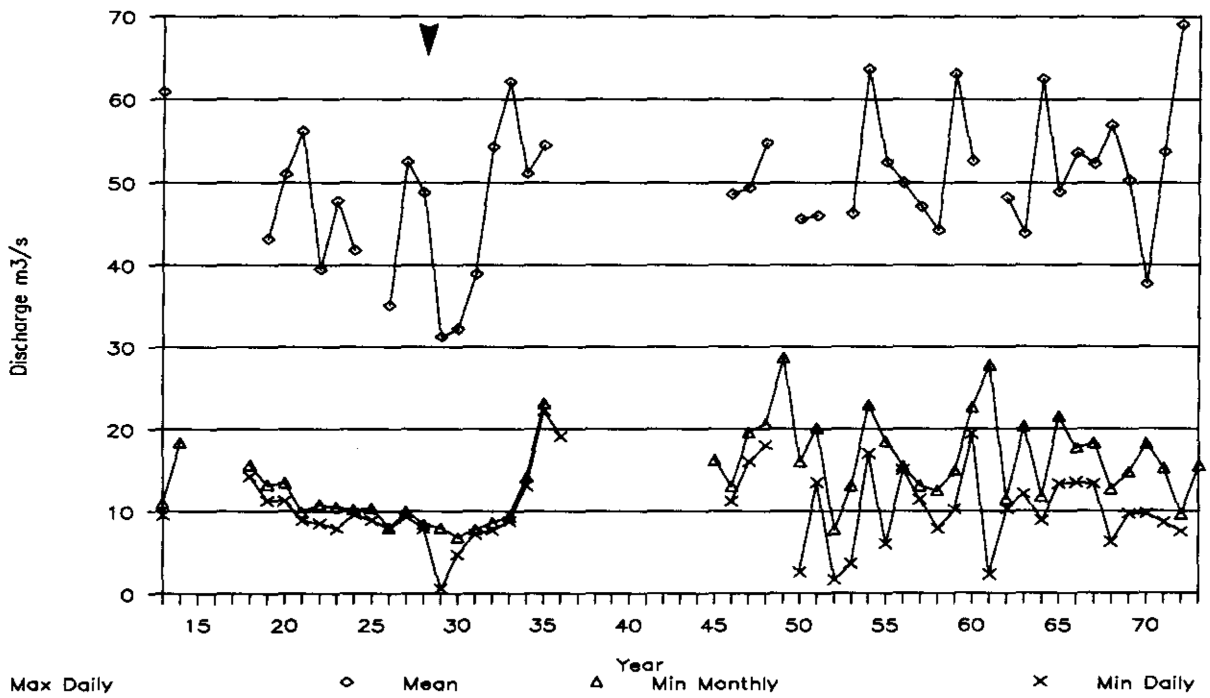
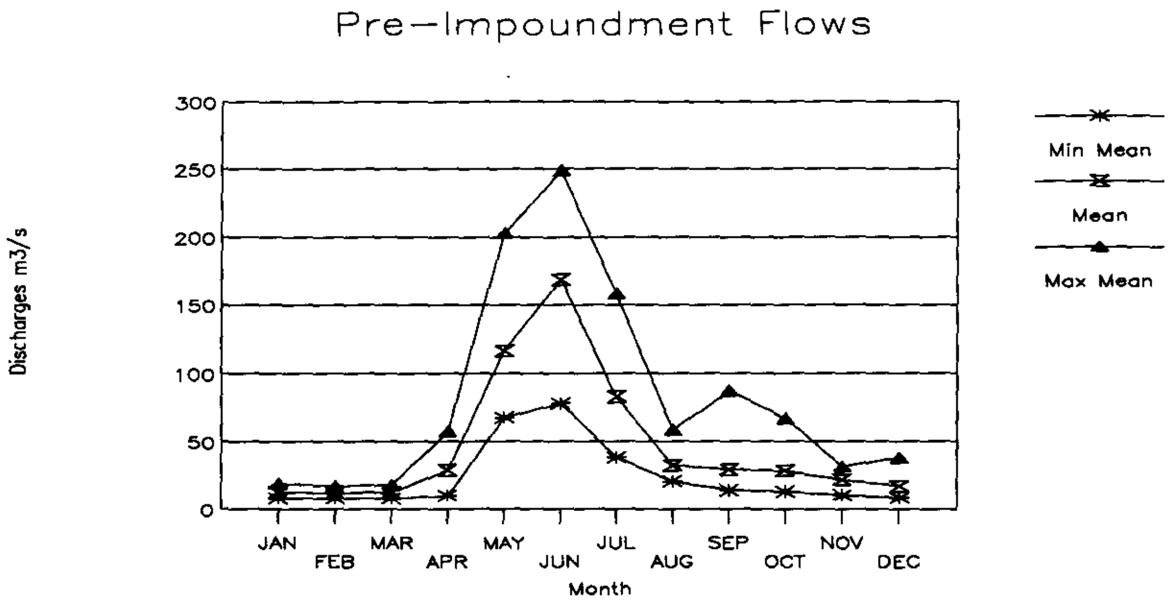


Figure 26. Pre- and post-impoundment annual flows in the Shuswap River below Wilsey Dam. Arrow indicates commencement of regulated regime. Data from Inland Waters Directorate (1988).



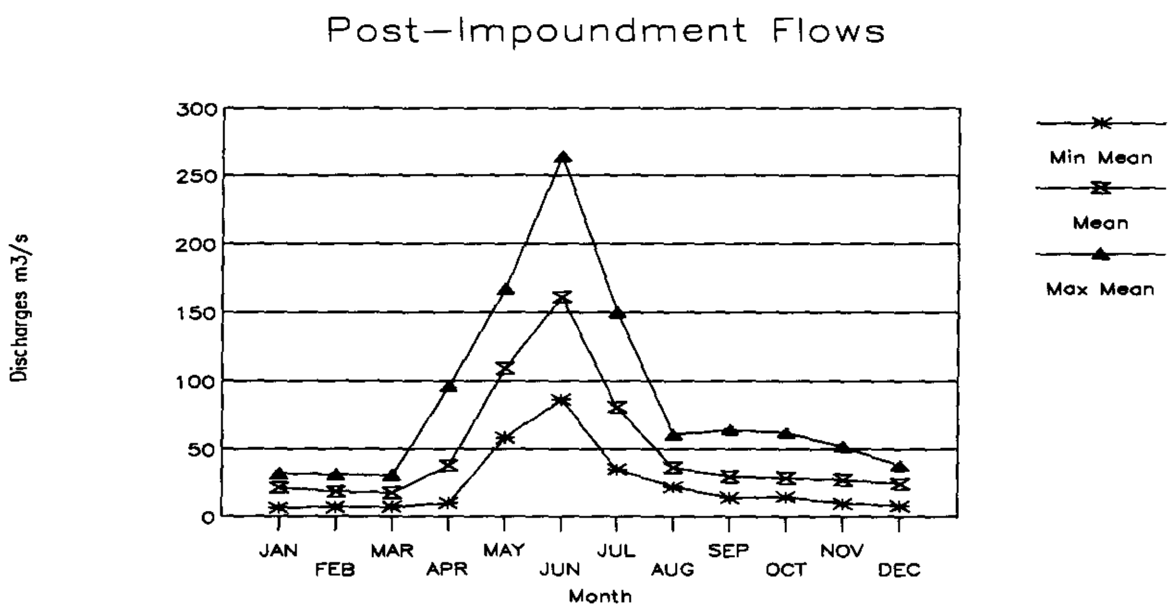


Figure 27. **Pre- and post-impoundment monthly flows in the Shuswap River below Wilsey Dam. Data from Inland Waters Directorate (1988).**

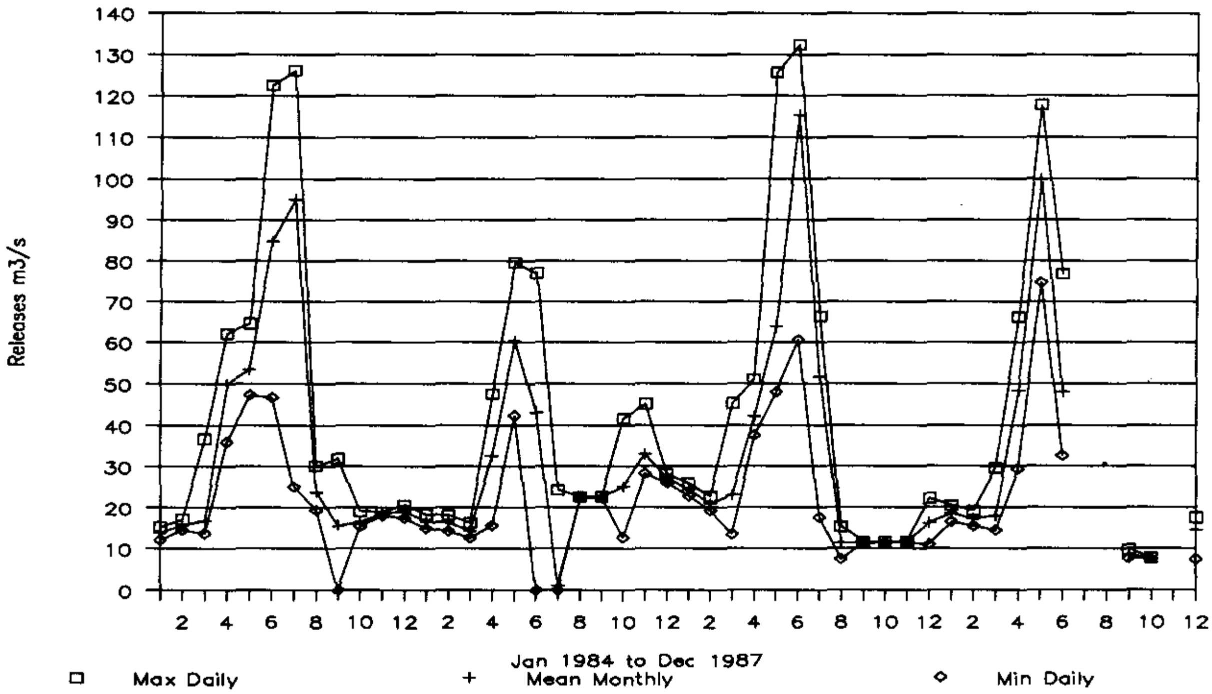


Figure 28. **Water releases from Sugar Lake through Peers Dam 1984 - 1987. Data from B.C. Hydro, Operations Control Department.**

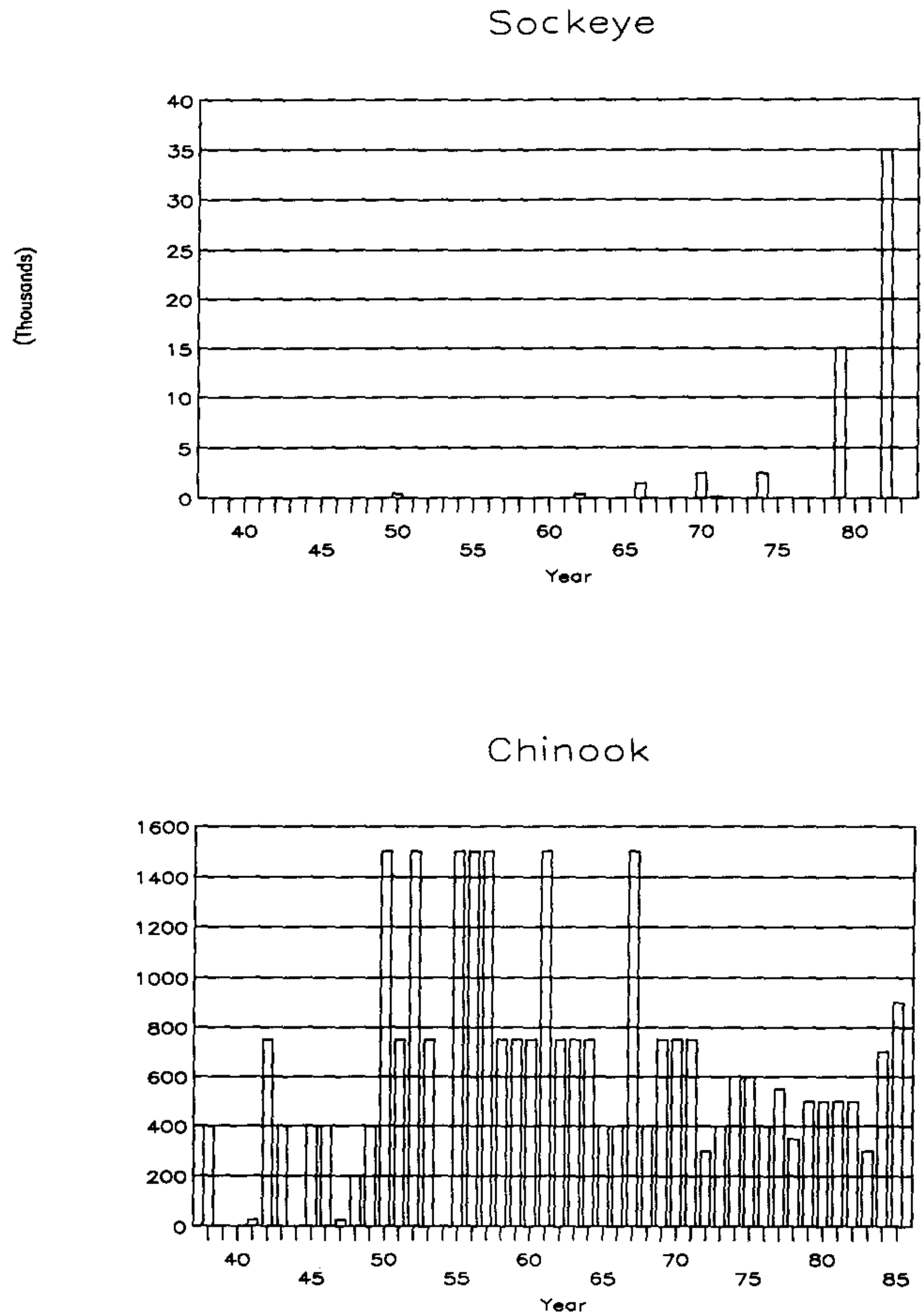
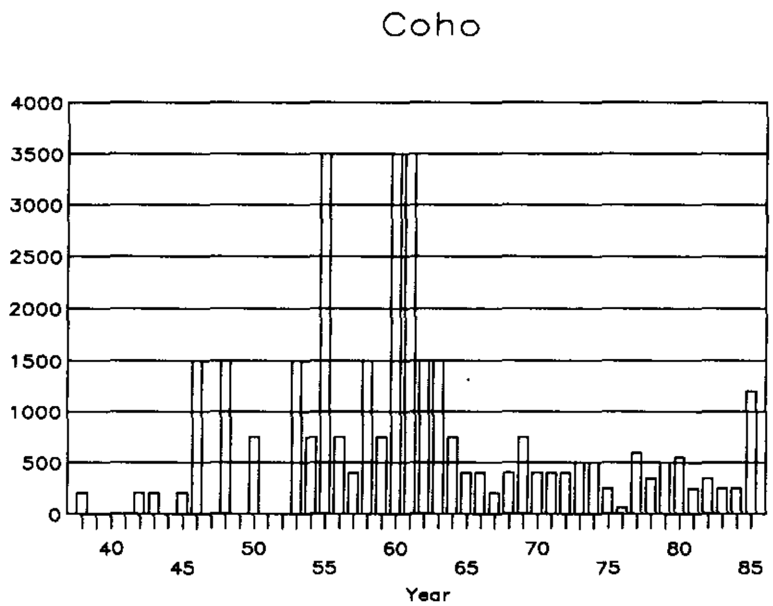


Figure 29. **Salmon escapements to the Middle Shuswap River. Data from Farwell et al. (1987) and DFO escapement records.**



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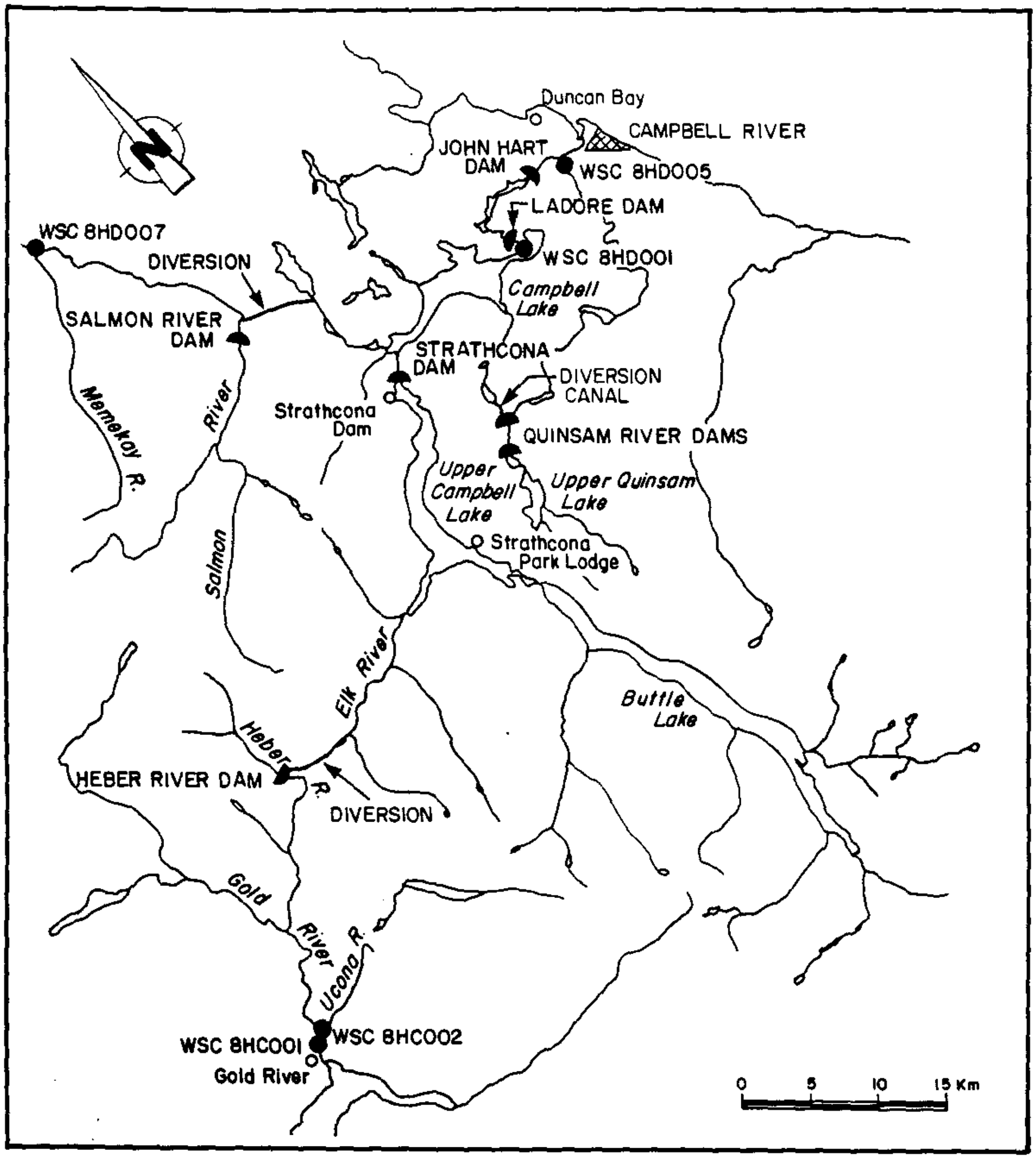


Figure 30. Location of the Campbell River hydroelectric developments.

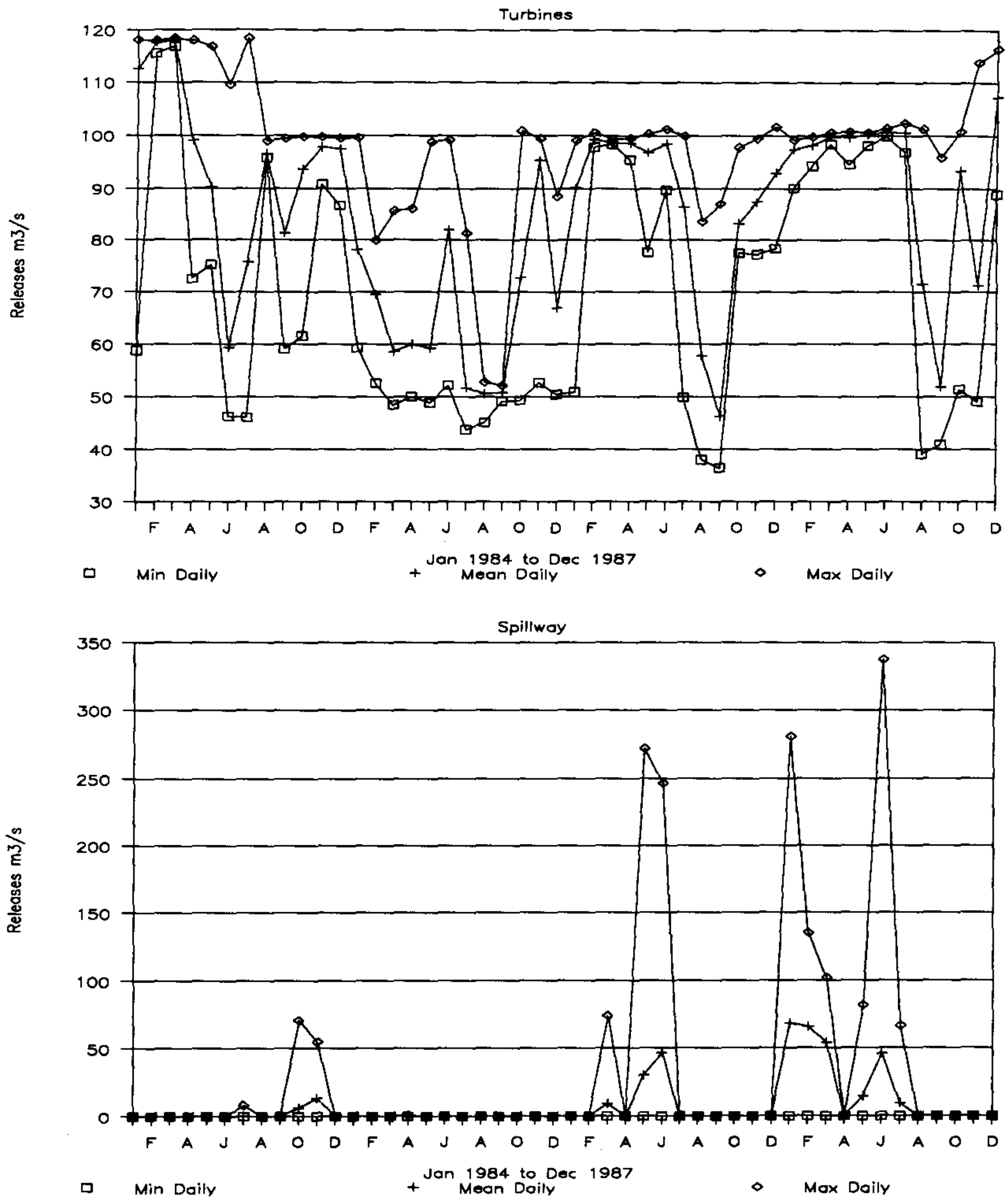


Figure 31. **Water releases through turbines and over spillway at John Hart Dam 1984 - 1987. Data from B.C. Hydro, Operations Control Department.**

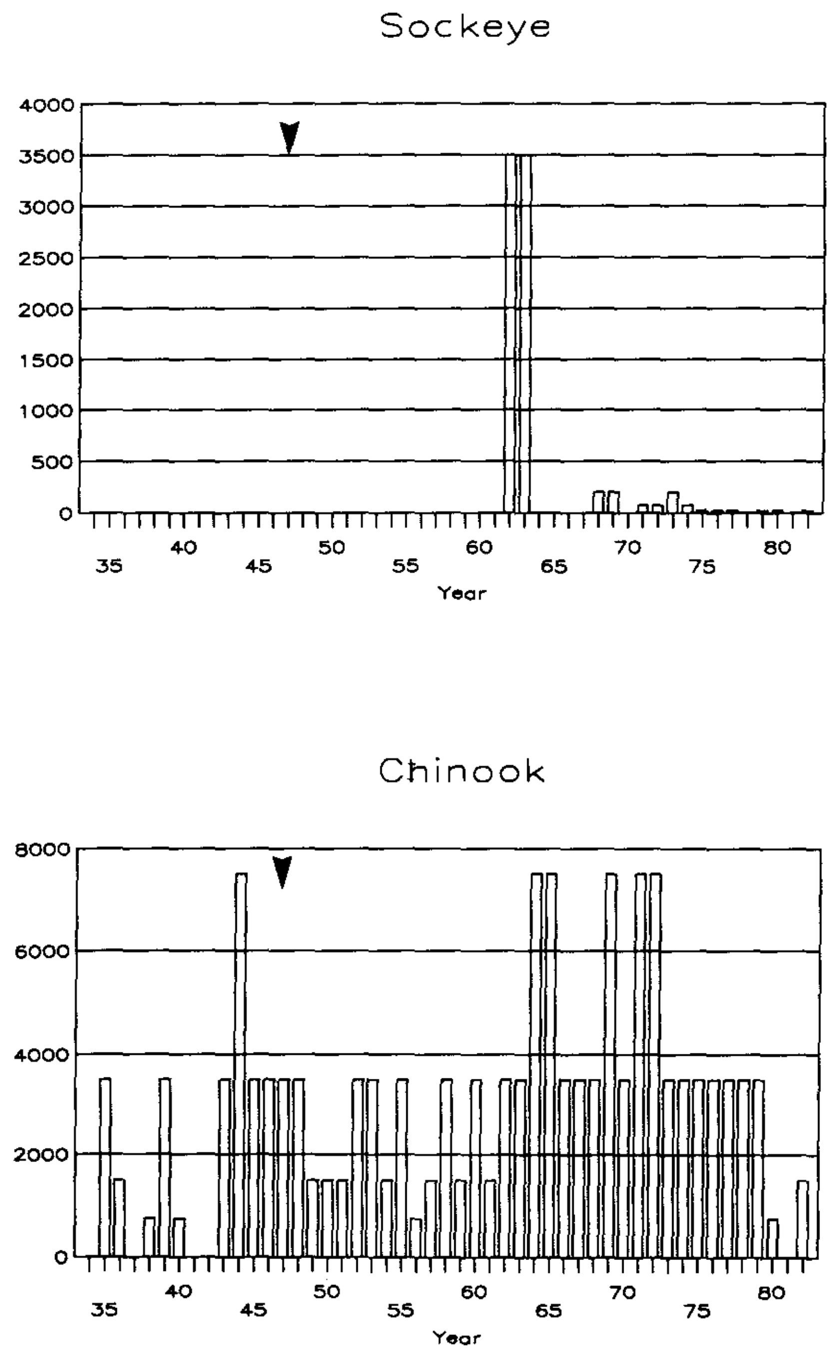


Figure 32. **Salmon escapements to Campbell River. Arrow indicates commencement of regulated flow regime. Data from DFO escapement records.**

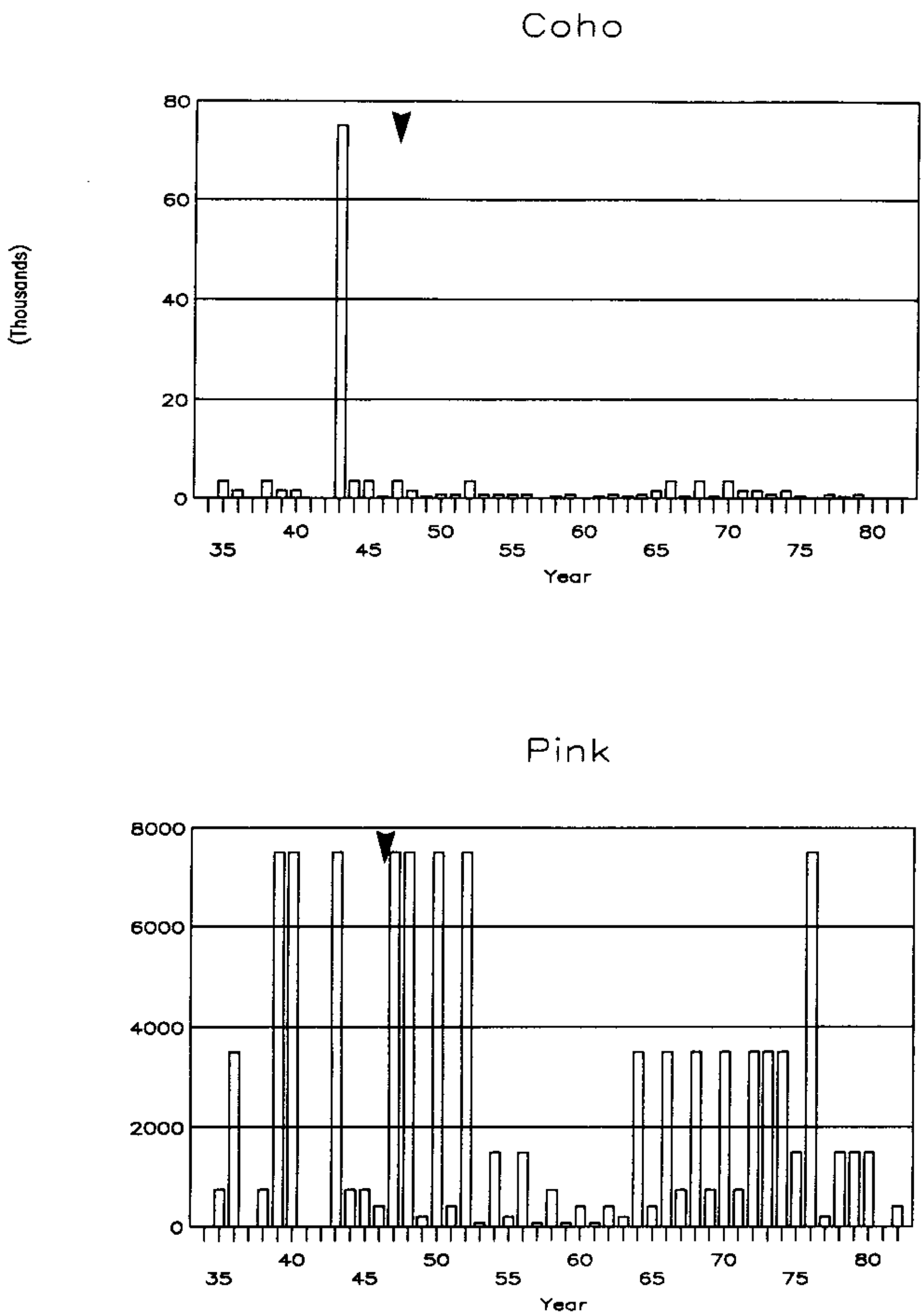


Figure 32. **Continued**

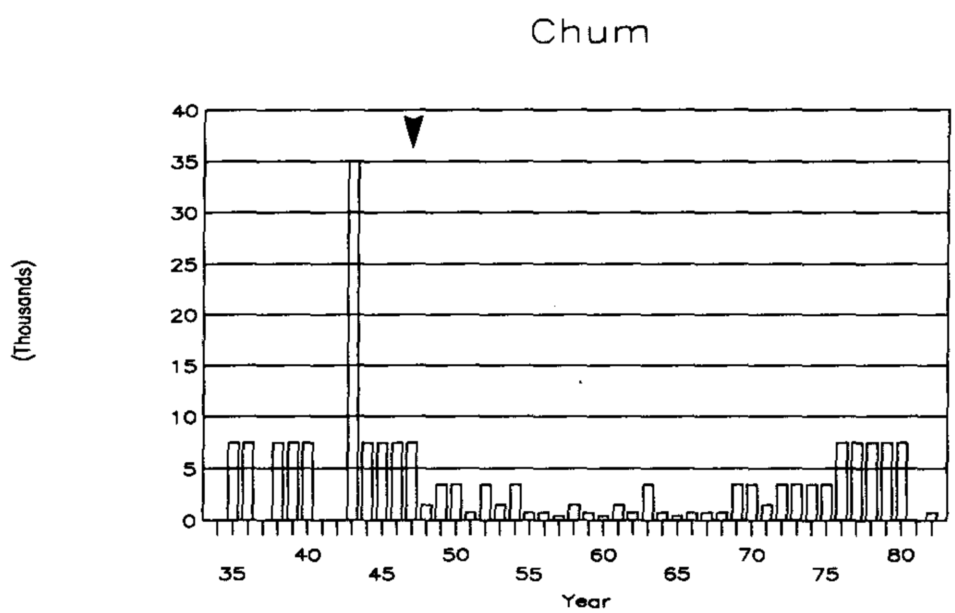


Figure 32. Continued

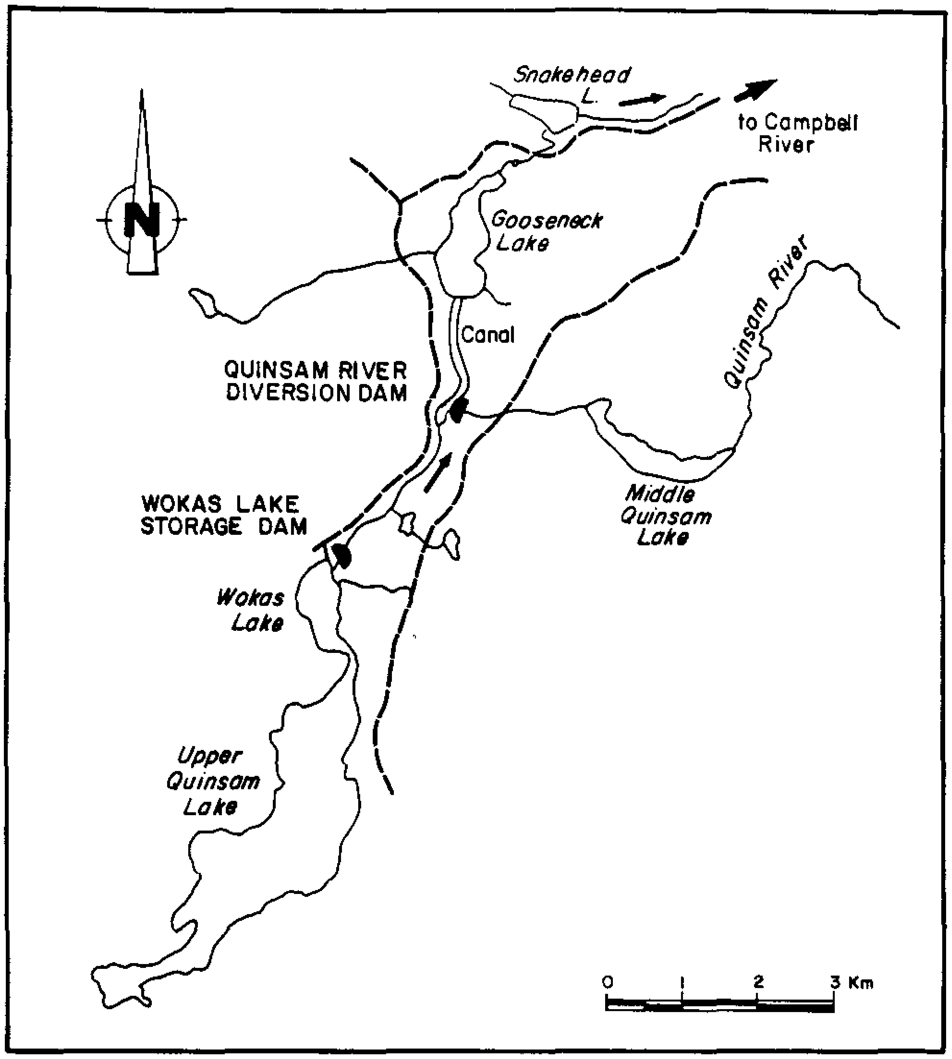


Figure 33. **Location of the Quinsam hydroelectric development.**

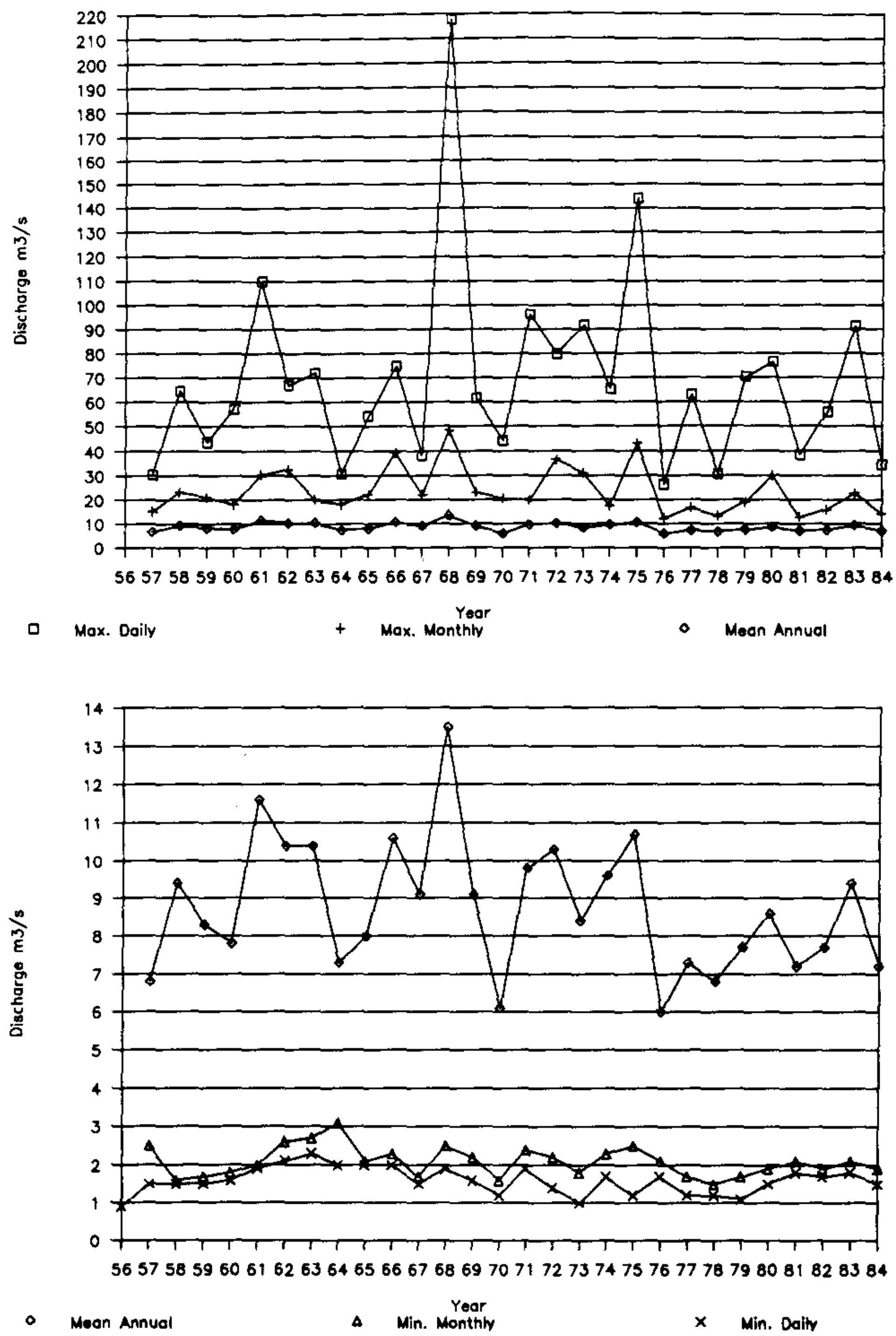


Figure 34. Post-impoundment annual flows in the Quinsam River. Data from Inland Waters Directorate (1988).

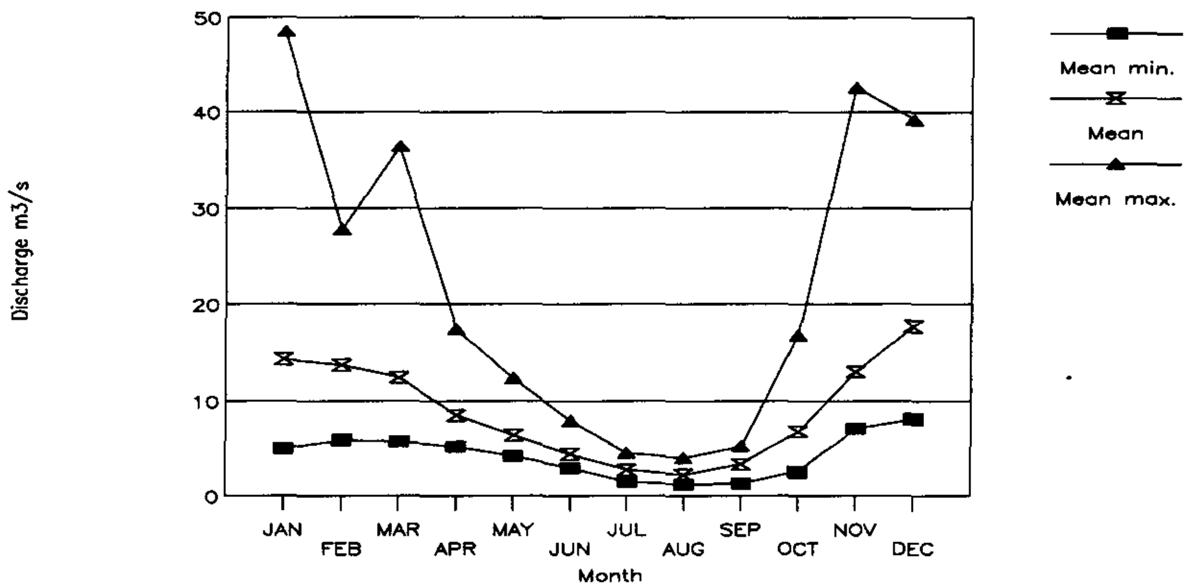


Figure 35. Post-impoundment monthly flows in the Quinsam River. Data from Inland Waters Directorate (1988).

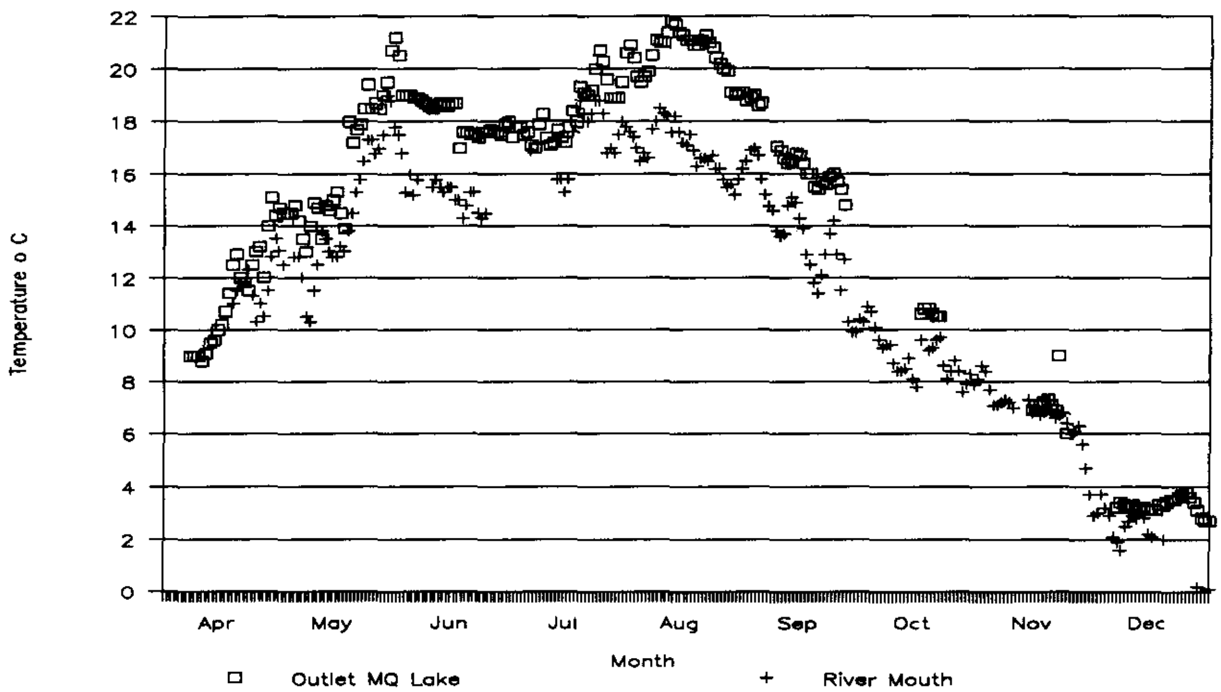


Figure 36. Spot water temperatures measured in Quinsam River, 1983. Data from Blackmun et al. (1985).

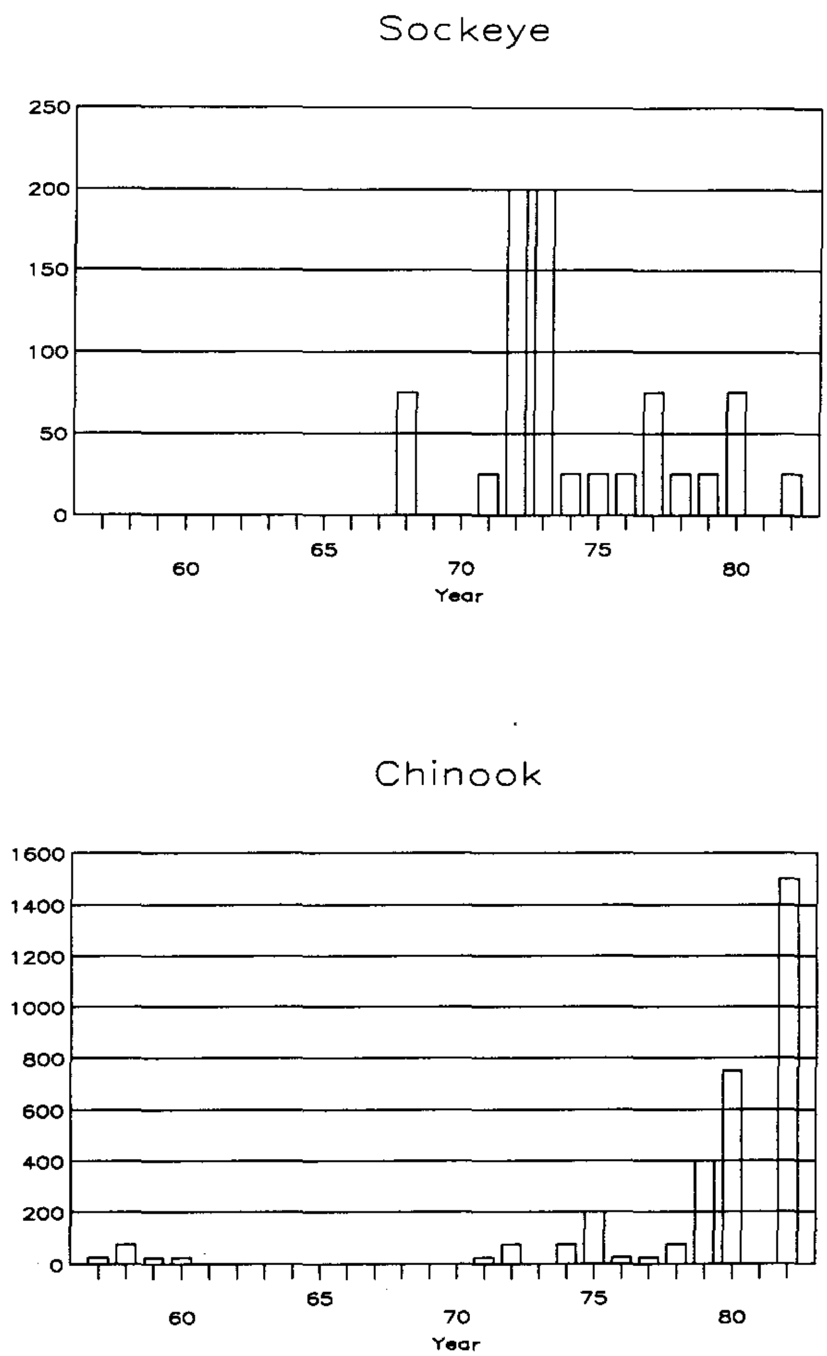
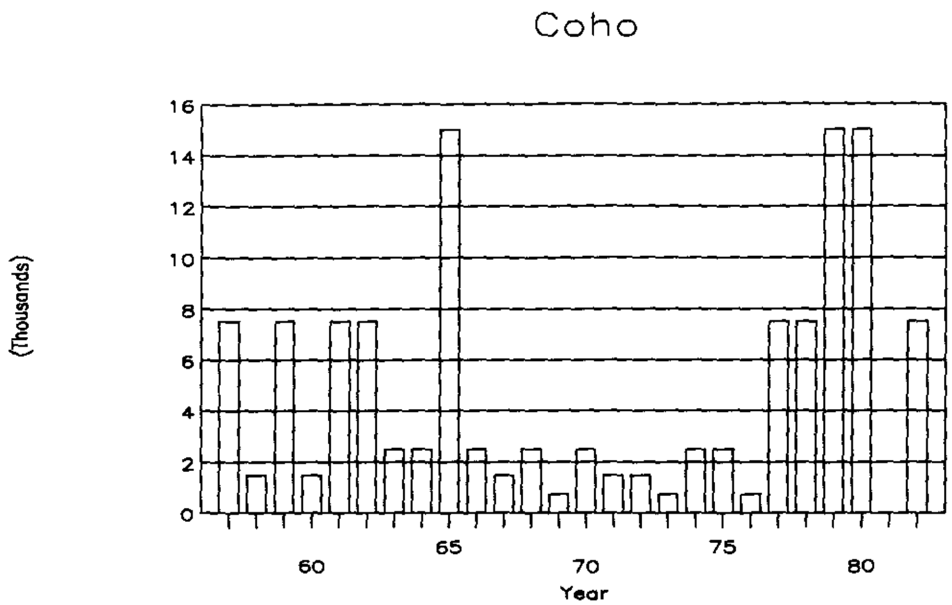


Figure 37. Salmon escapements to Quinsam River. Data from DFO escapement records.



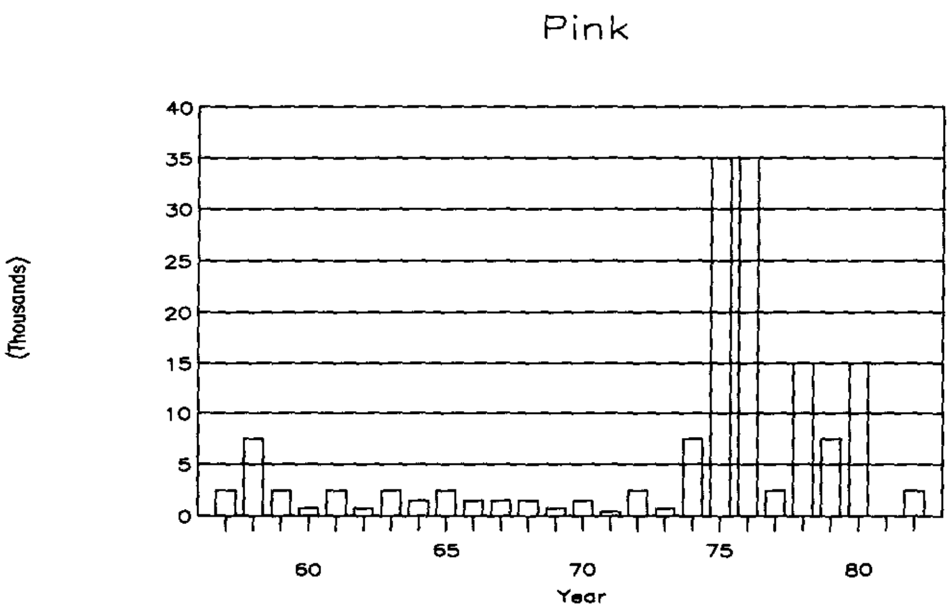
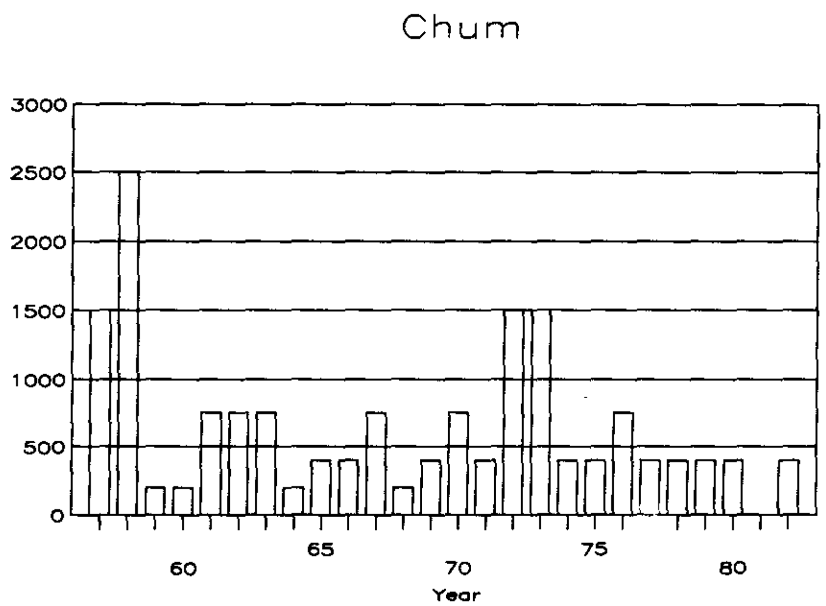


Figure 37. Continued



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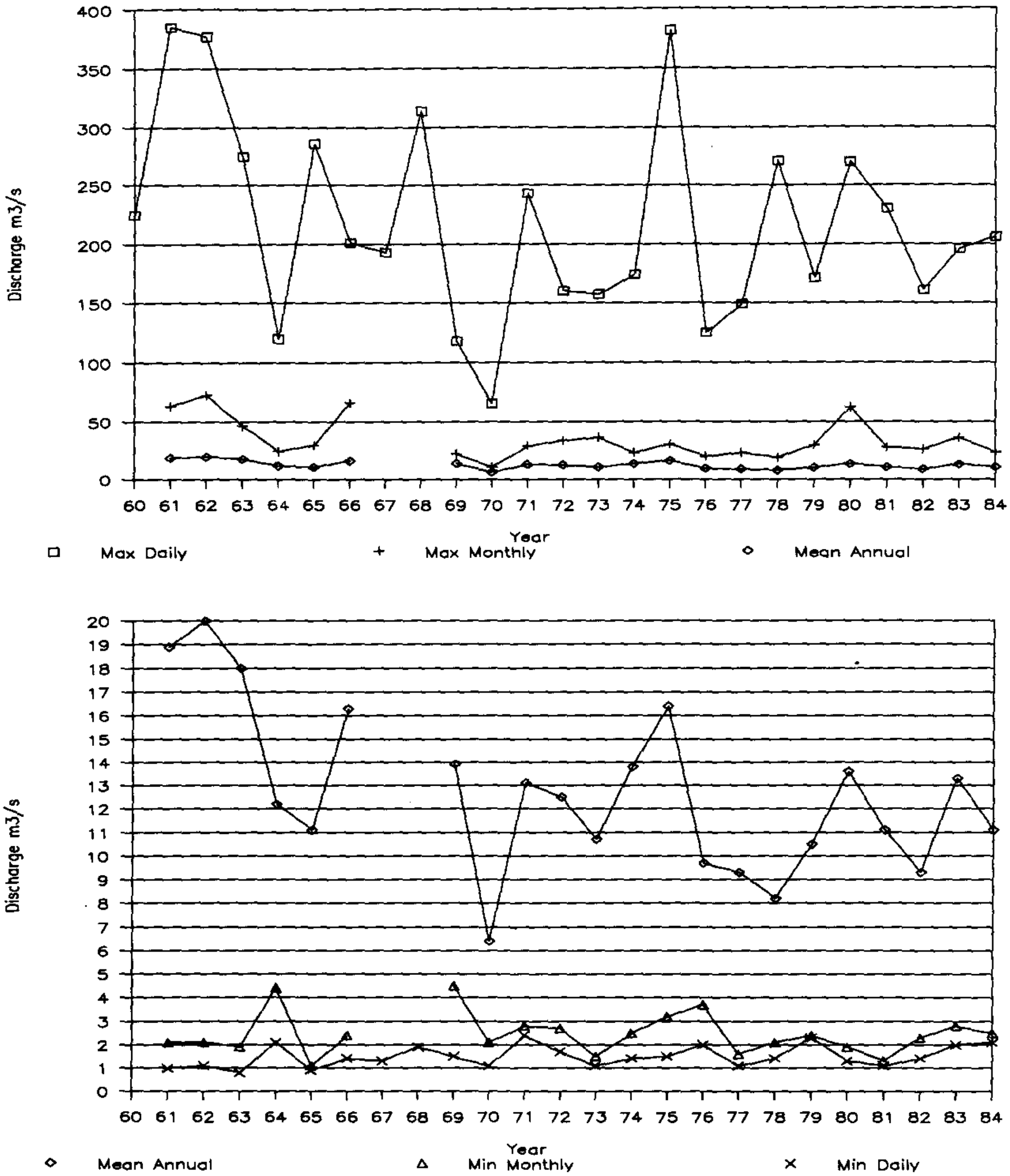


Figure 38. Post-impoundment annual flows in the Salmon River above the Memekay River confluence. Data from Inland Waters Directorate (1988).

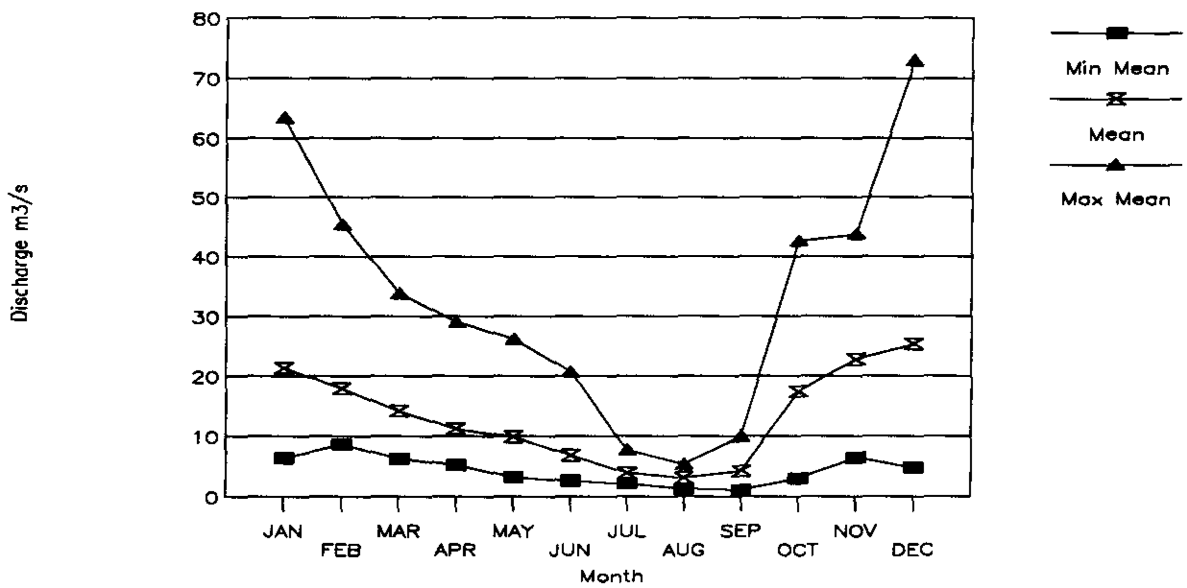


Figure 39. Post-diversion monthly flows in the Salmon River above the Memekay River confluence. Data from Inland Waters Directorate (1988).

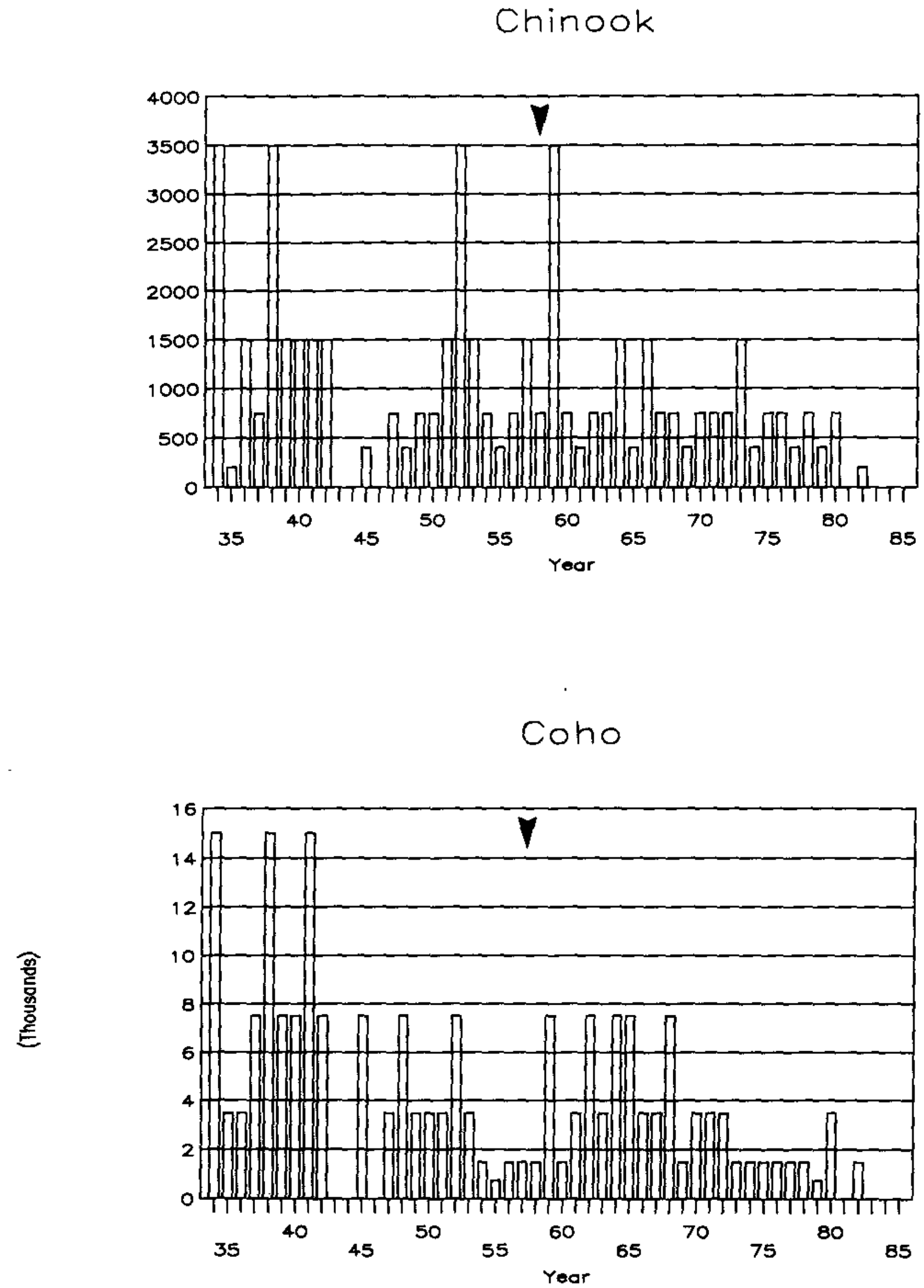
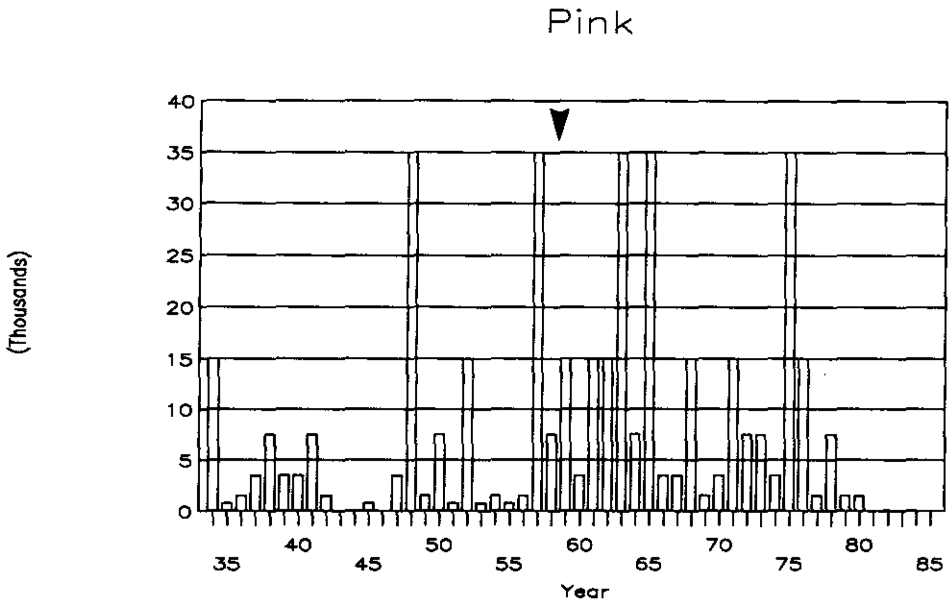


Figure 40. Salmon escapements to the Salmon River. Arrow indicates commencement of regulated regime. Data from DFO escapement records.



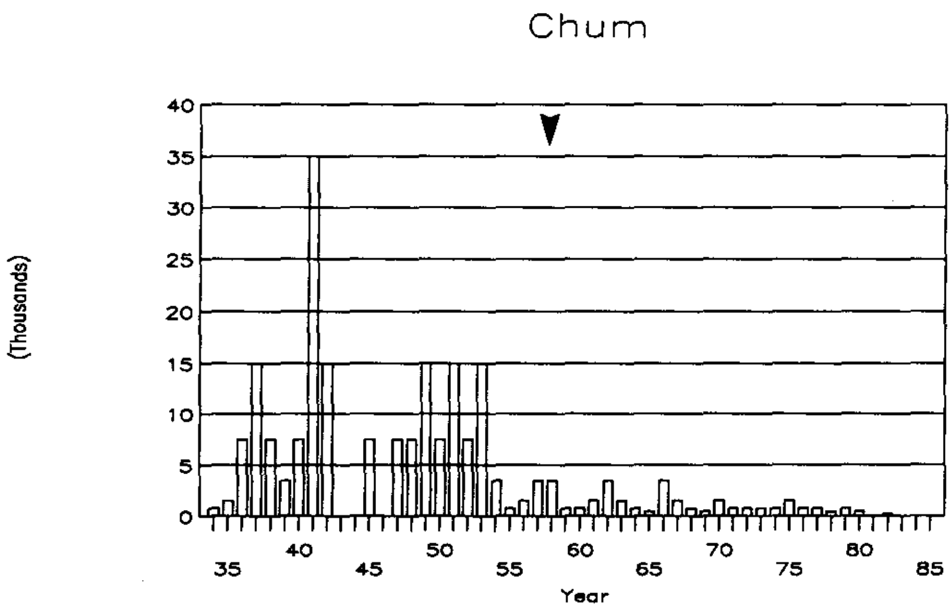


Figure 40. Continued

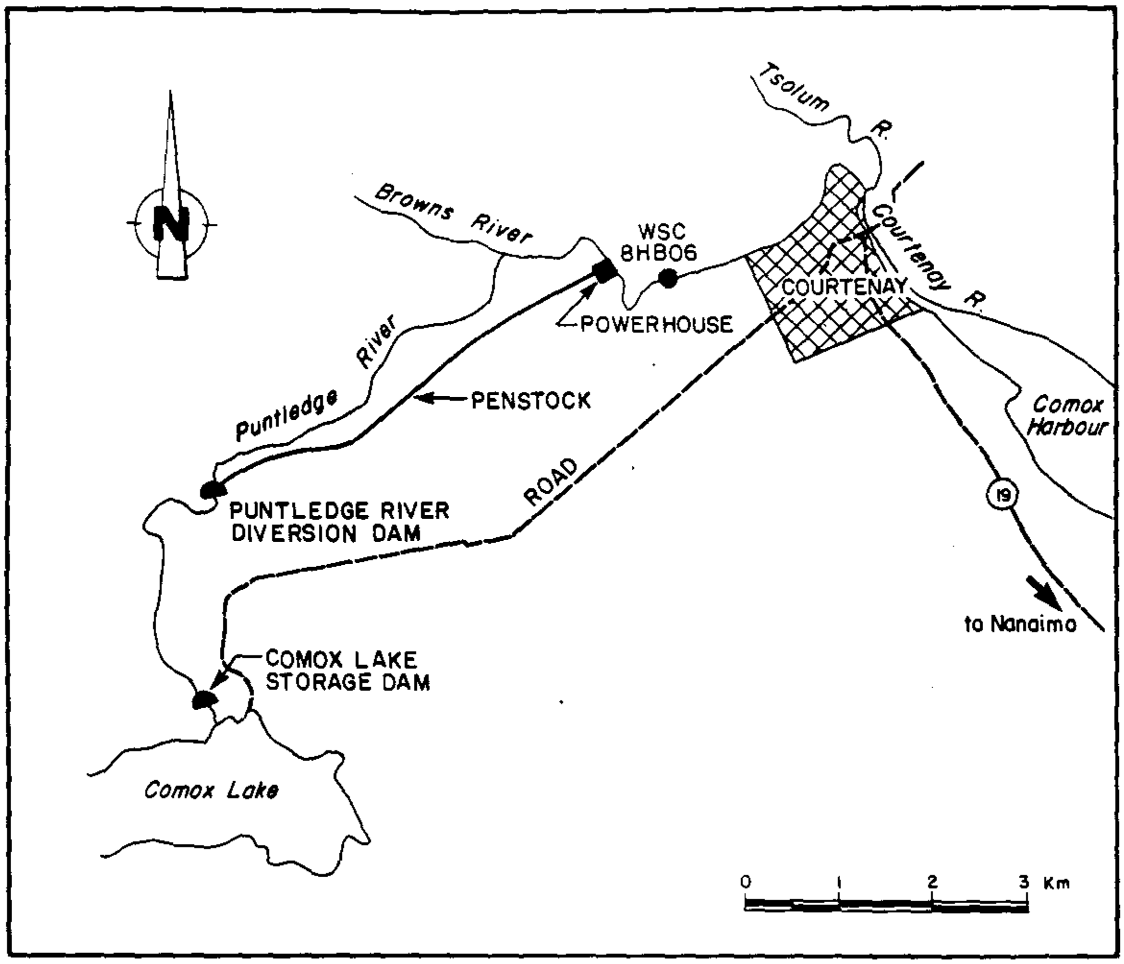
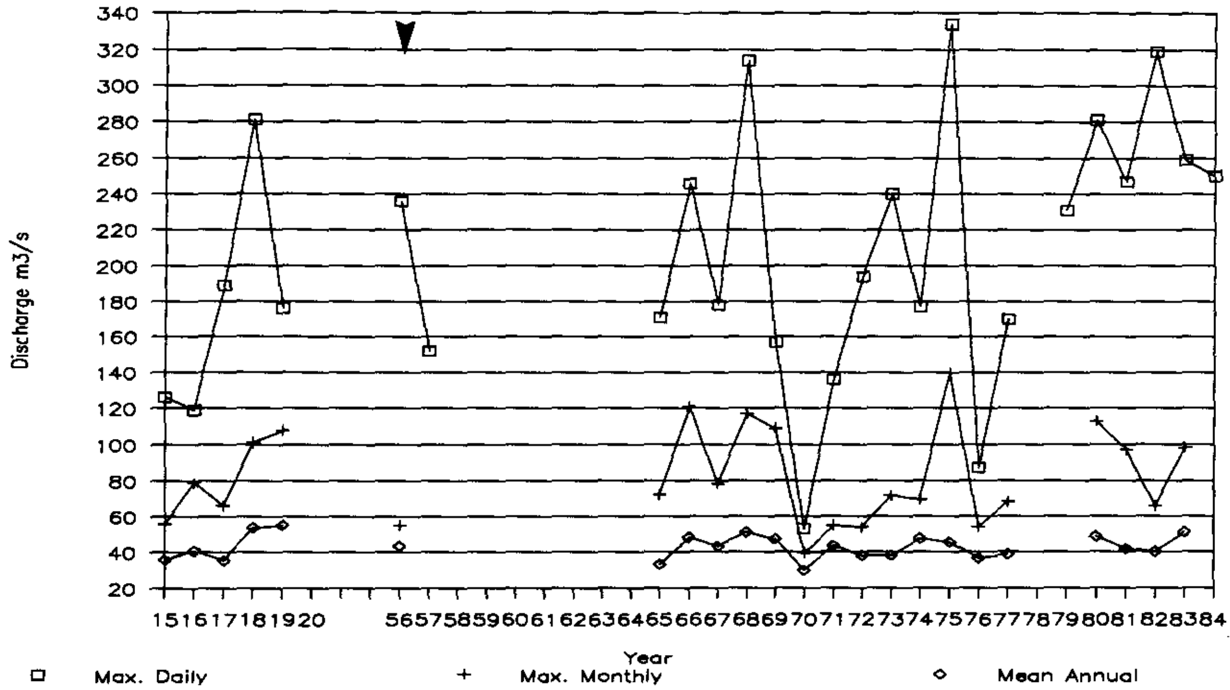


Figure 41. Location of the Puntledge hydroelectric development.



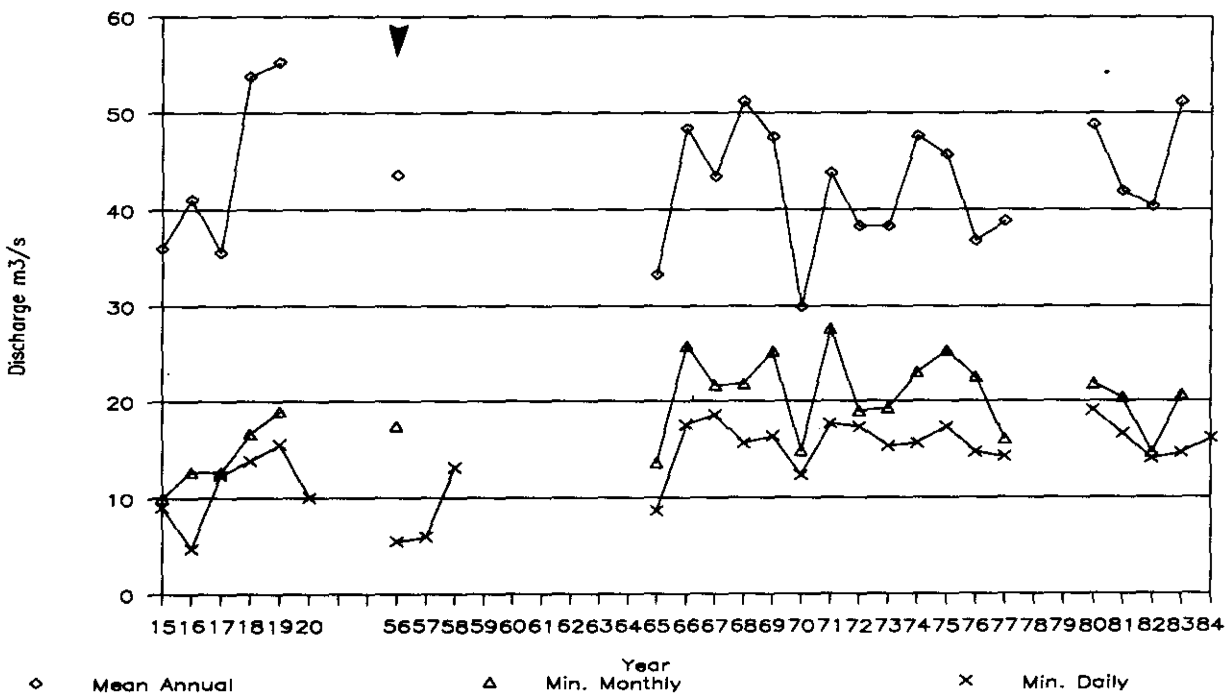


Figure 42. Pre- and post-impoundment annual flows in the Puntledge River. Arrow indicates commencement of regulated regime. Data from Inland Waters Directorate (1988).

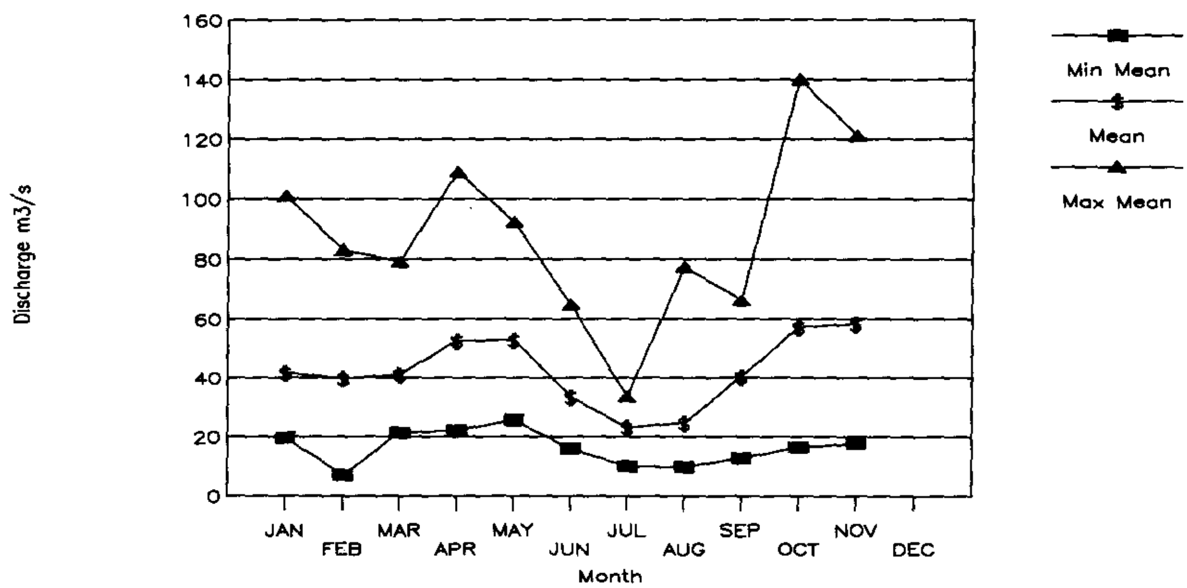


Figure 43. **Post-impoundment monthly flows in the Puntledge River. Data from Inland Waters Directorate (1988).**

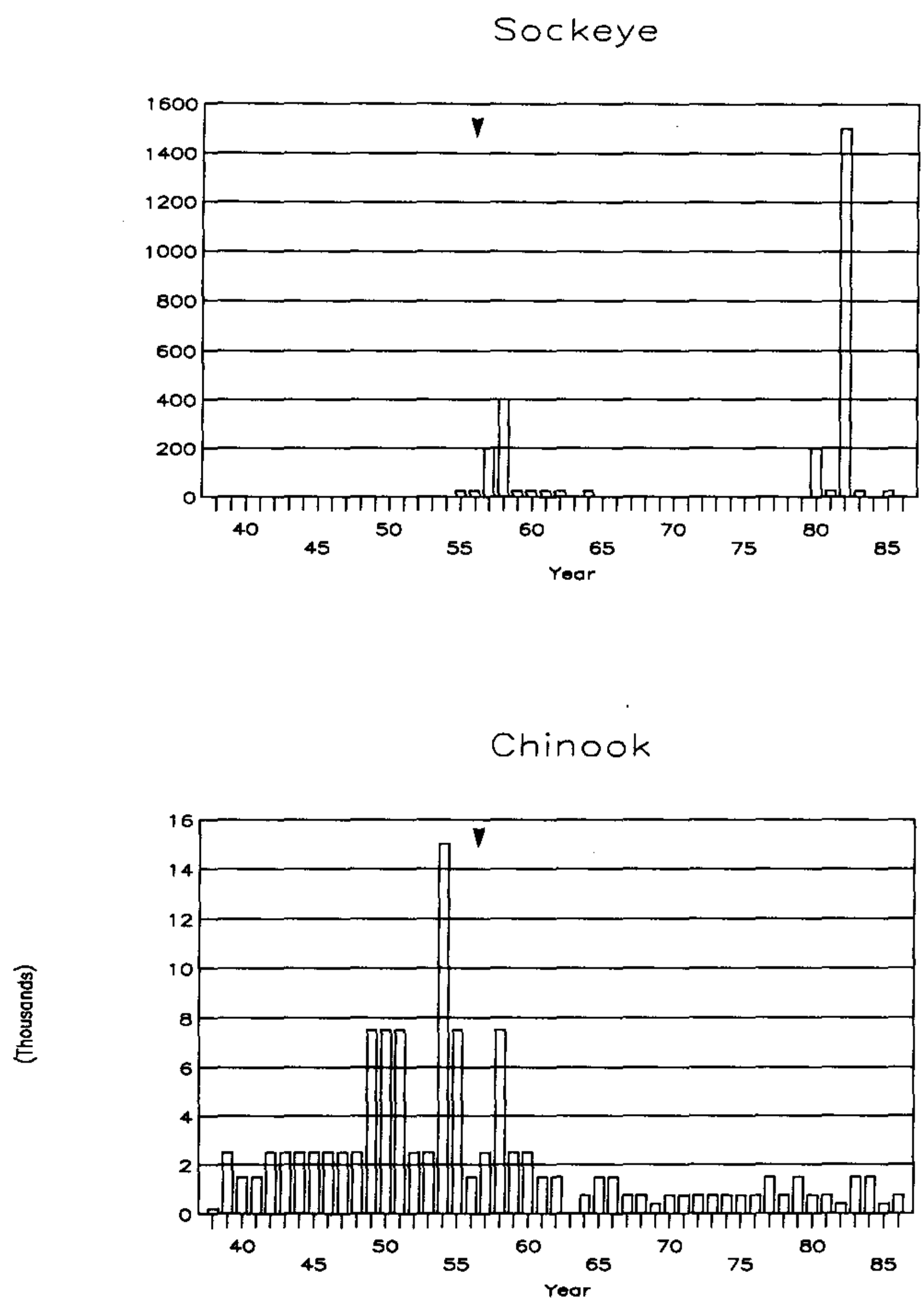
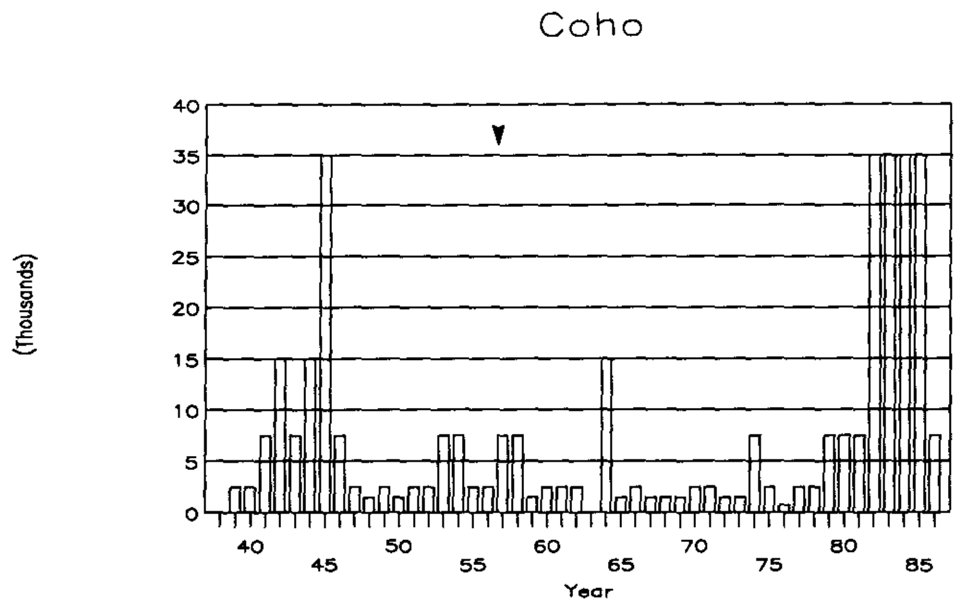


Figure 44. Salmon escapements to Puntledge River. Arrow indicates commencement of regulated flow regime. Data from DFO escapement records.



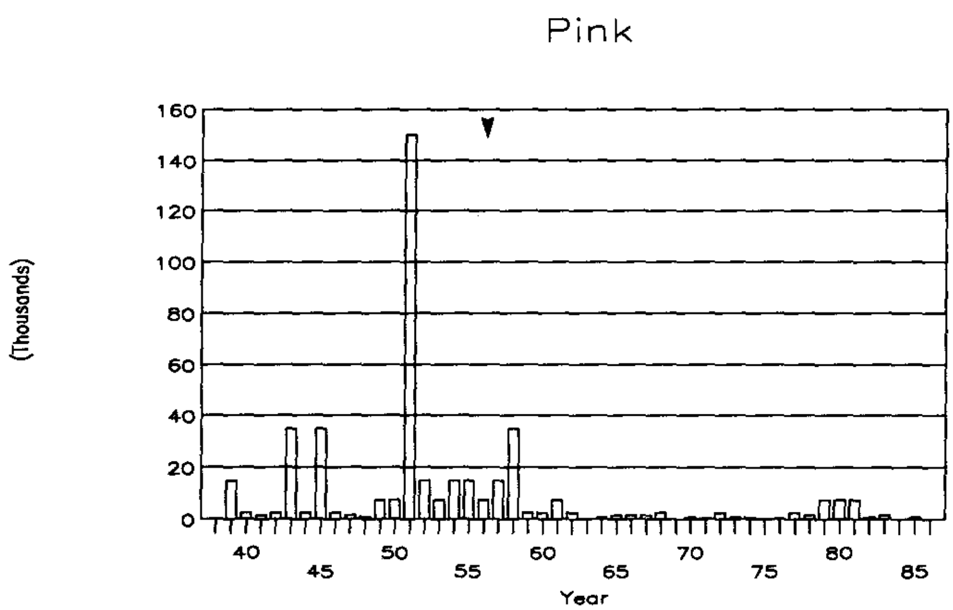


Figure 44. Continued

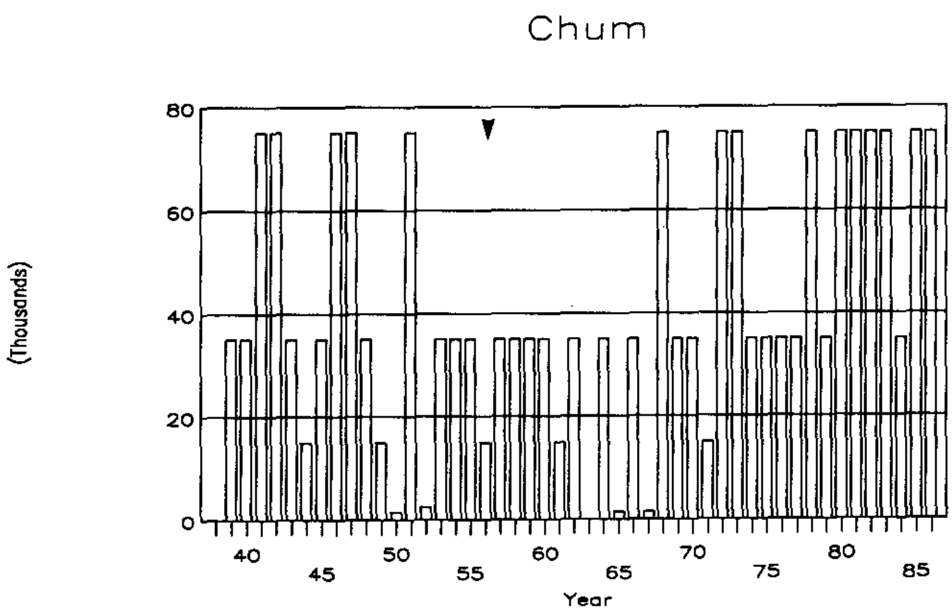


Figure 44. Continued

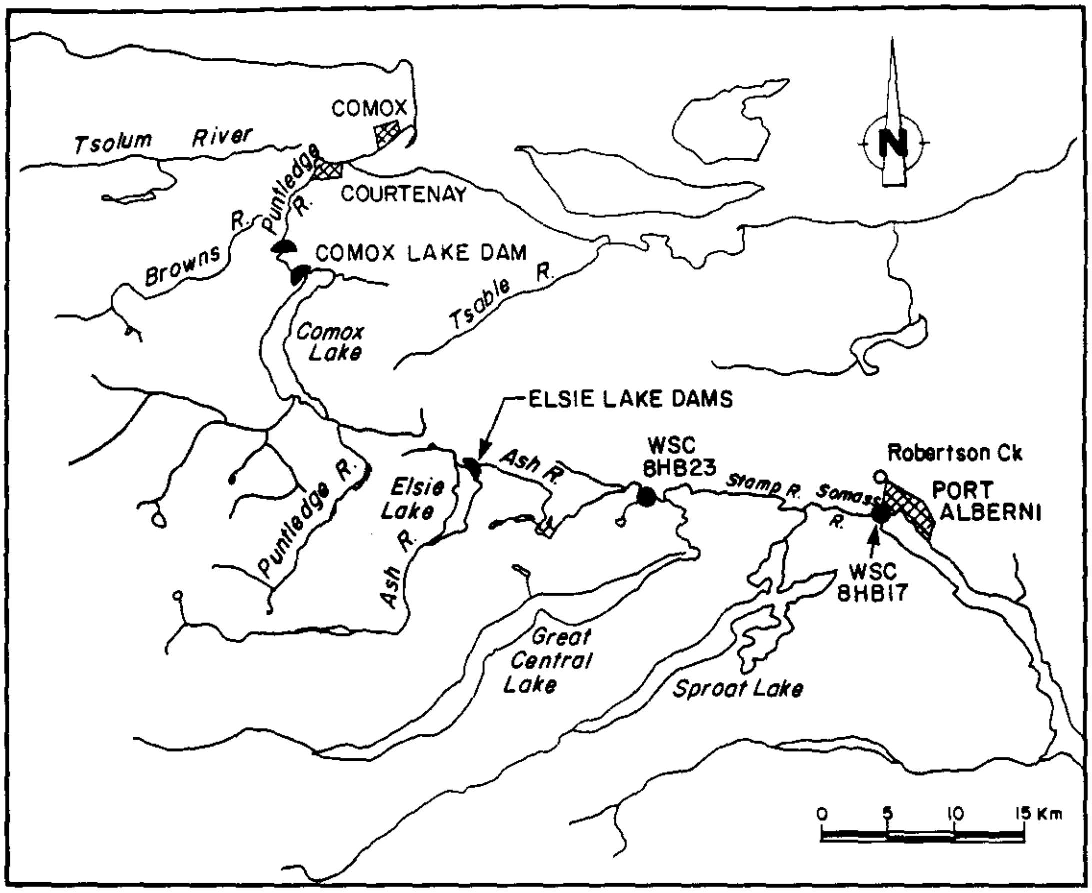
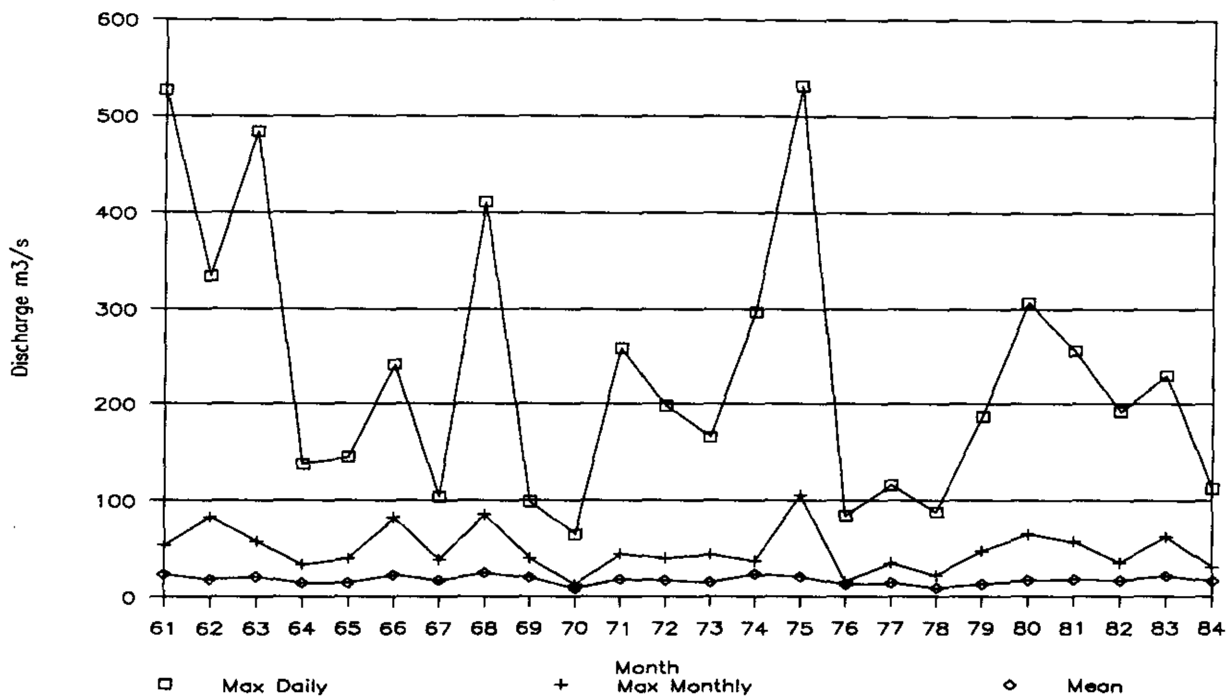


Figure 45. Location of the Ash River hydroelectric development.



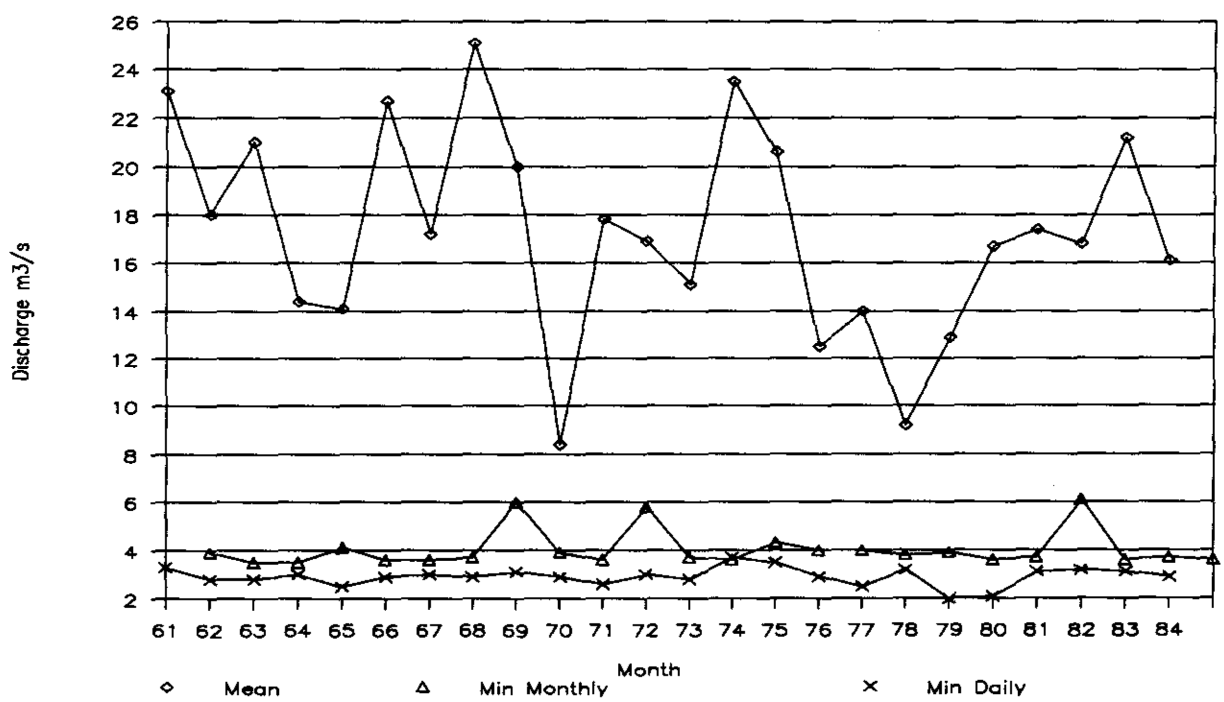


Figure 46. **Post-impoundment annual flows in the Ash River. Data from Inland Waters Directorate (1988).**

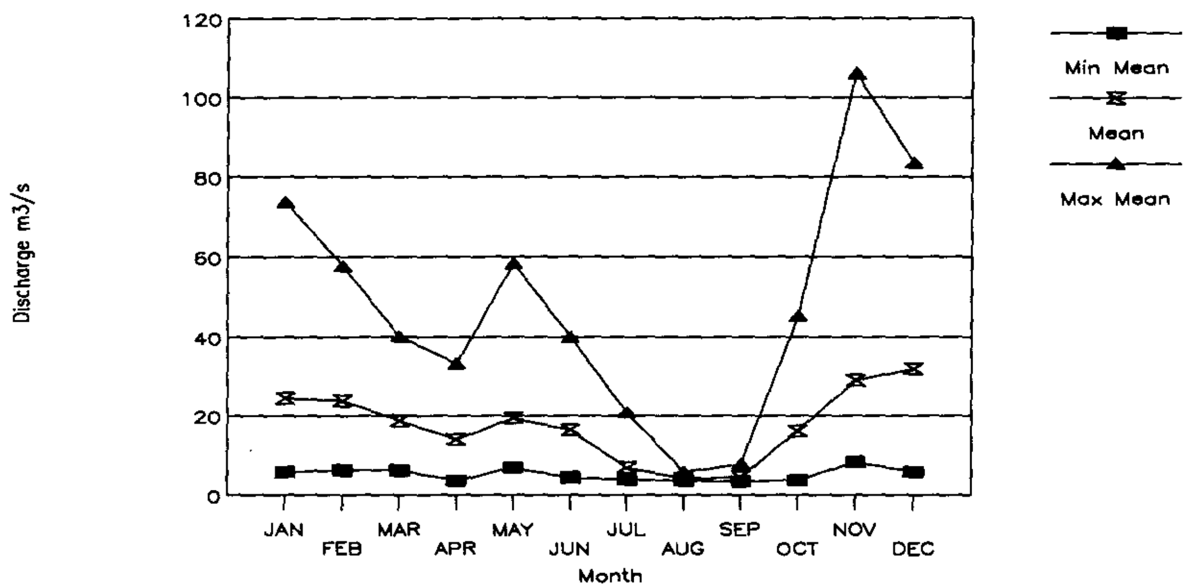


Figure 47. Post-impoundment monthly flows in the Ash River. Data from Inland Waters Directorate (1988).

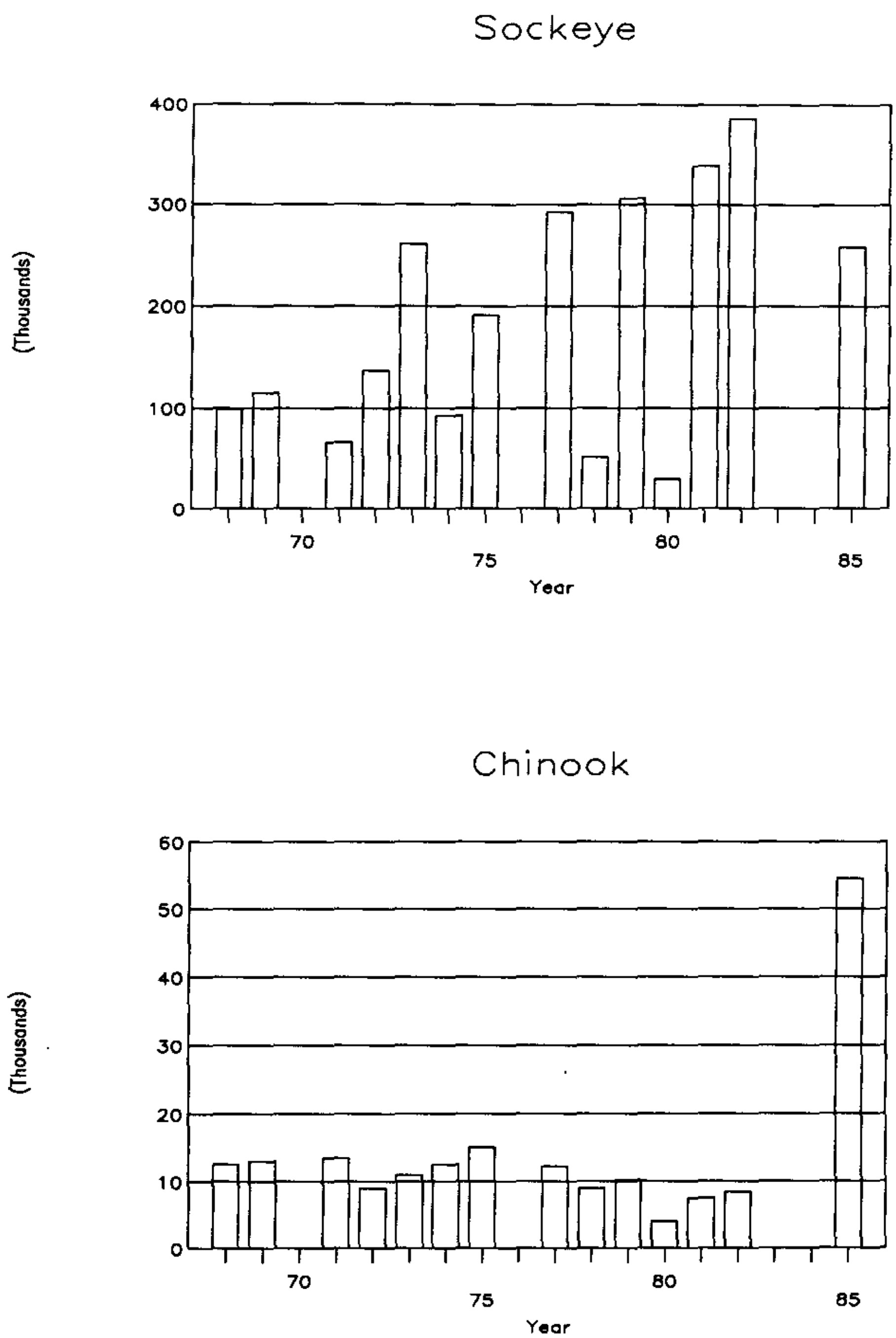


Figure 48. Salmon escapements to the Somass River. Data from DFO escapement records.

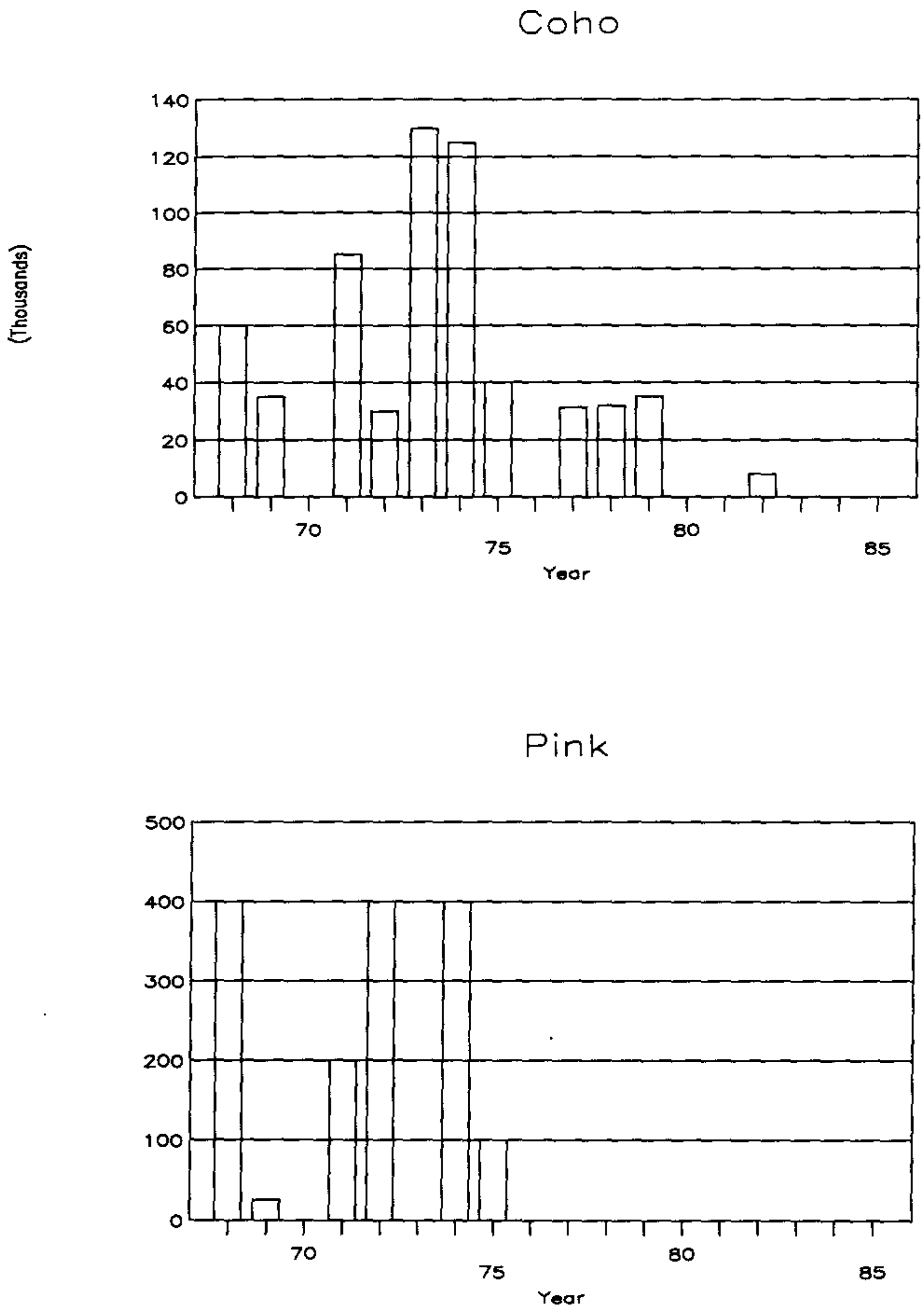


Figure 48. Continued

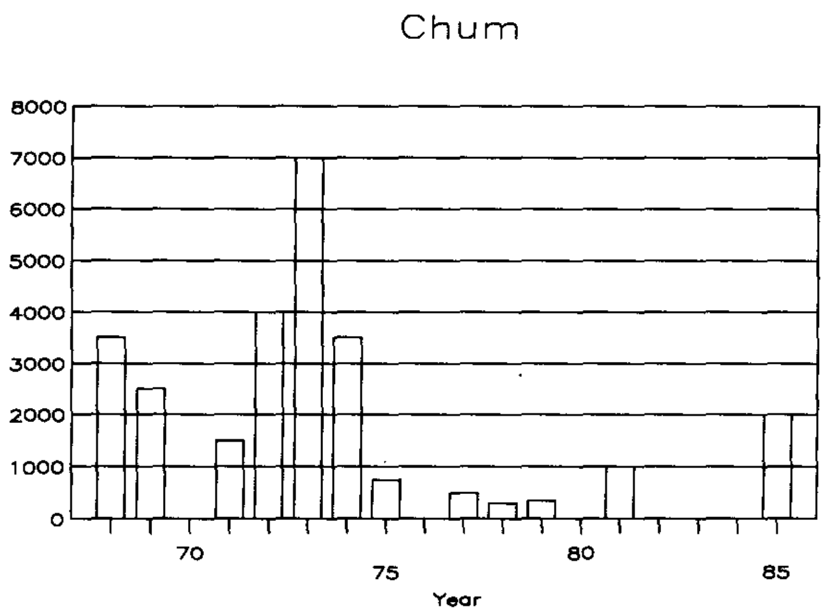


Figure 48. Continued

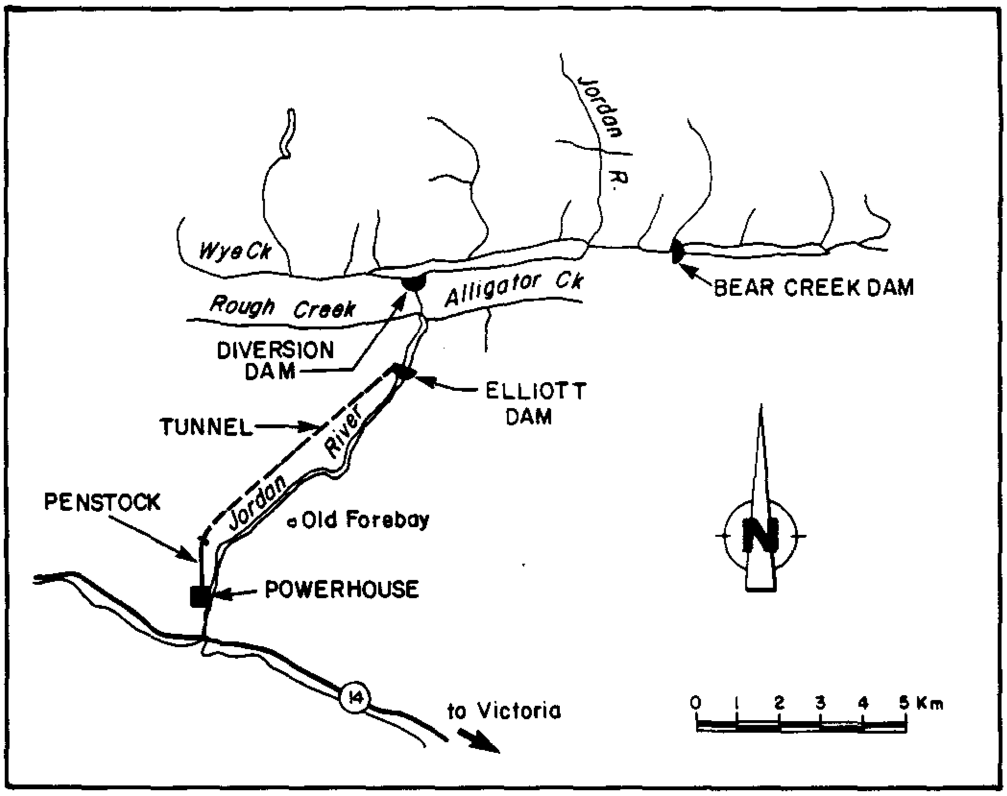


Figure 49. **Location of the Jordan River hydroelectric development.**

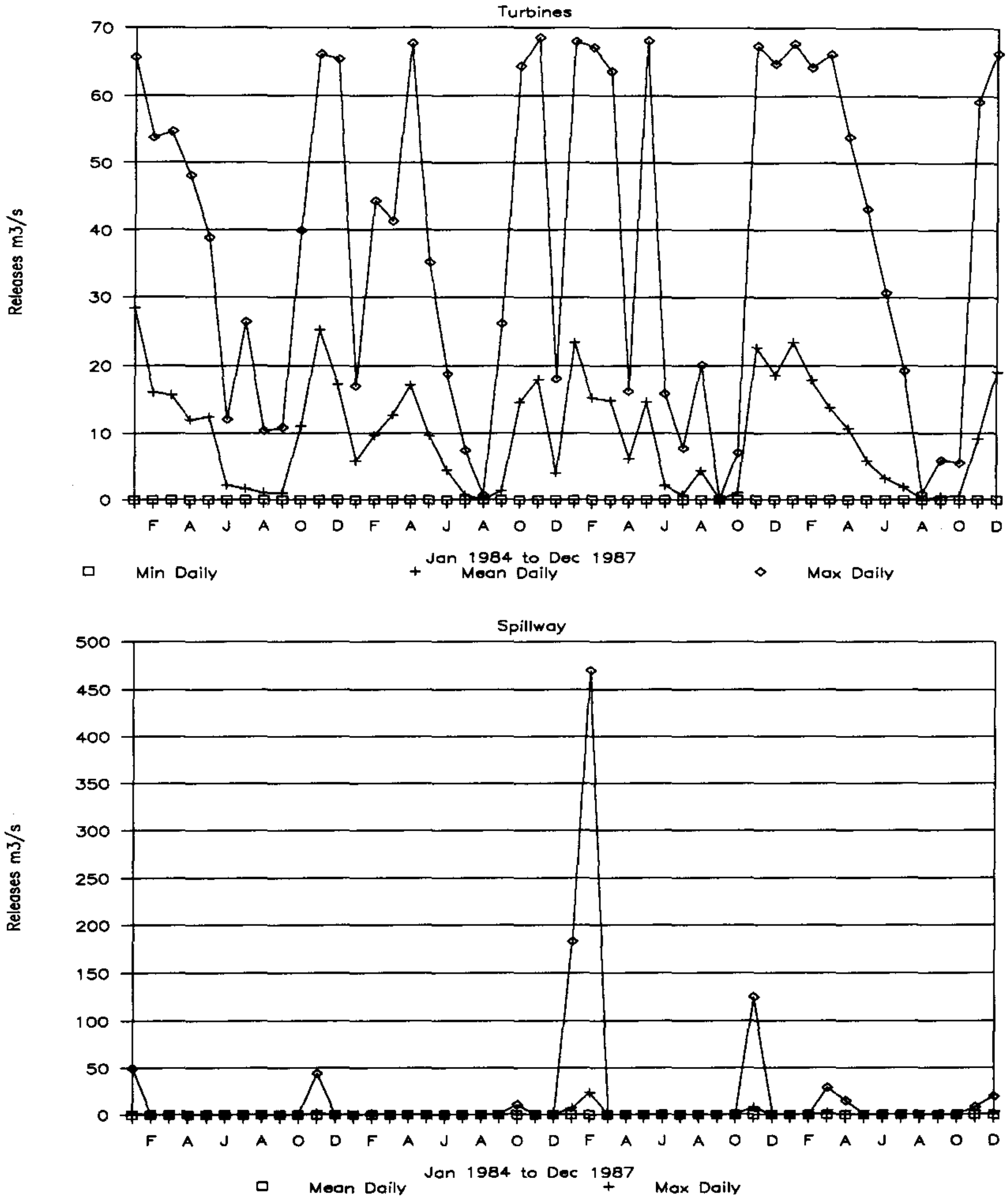
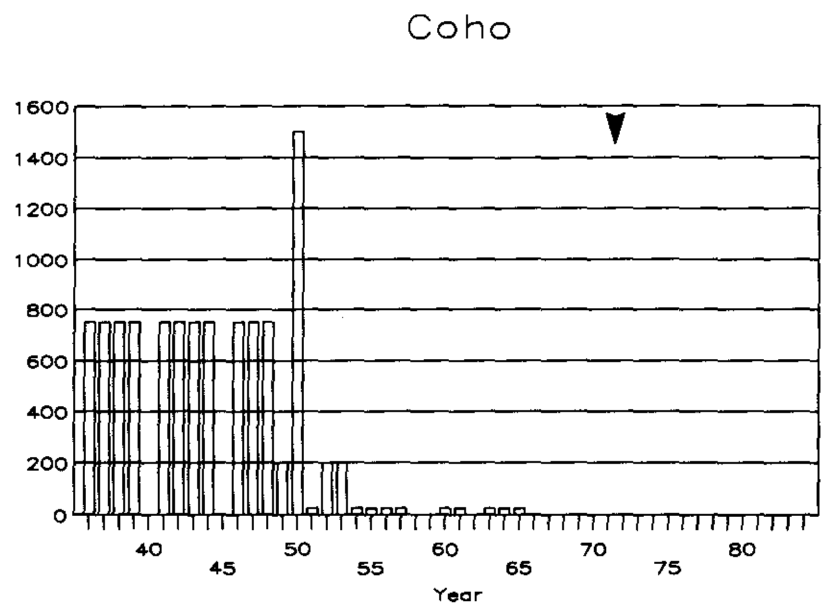


Figure 50. **Water releases through turbines and over spillway at the Elliott Dam 1984 - 1987. Data from B.C. Hydro, Operations Control Department.**



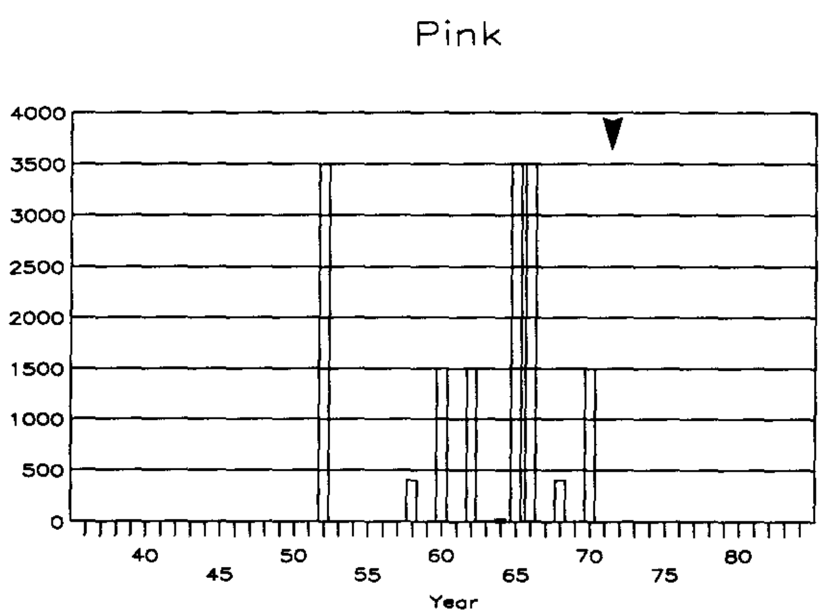


Figure 51. Salmon escapements to the Jordan River. Arrow indicates commencement of regulated regime. Data from DFO escapement records.

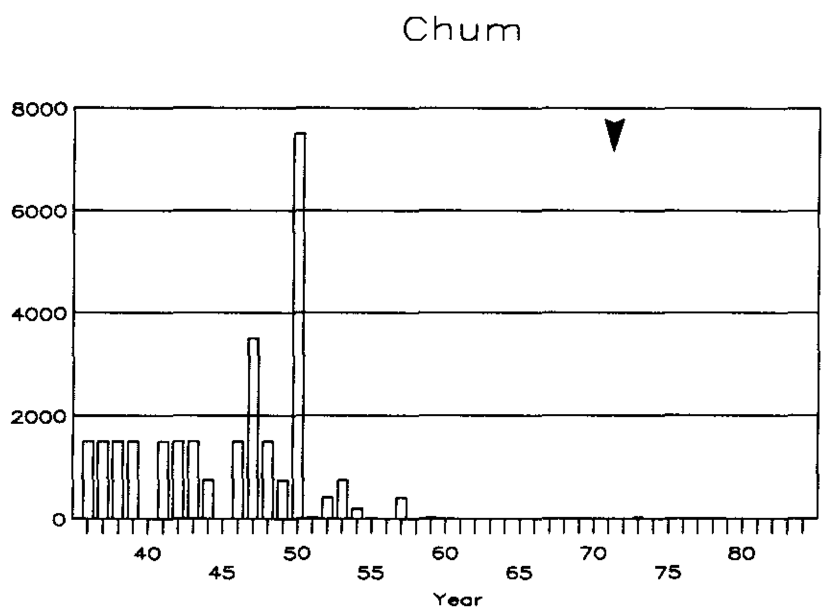


Figure 51. Continued

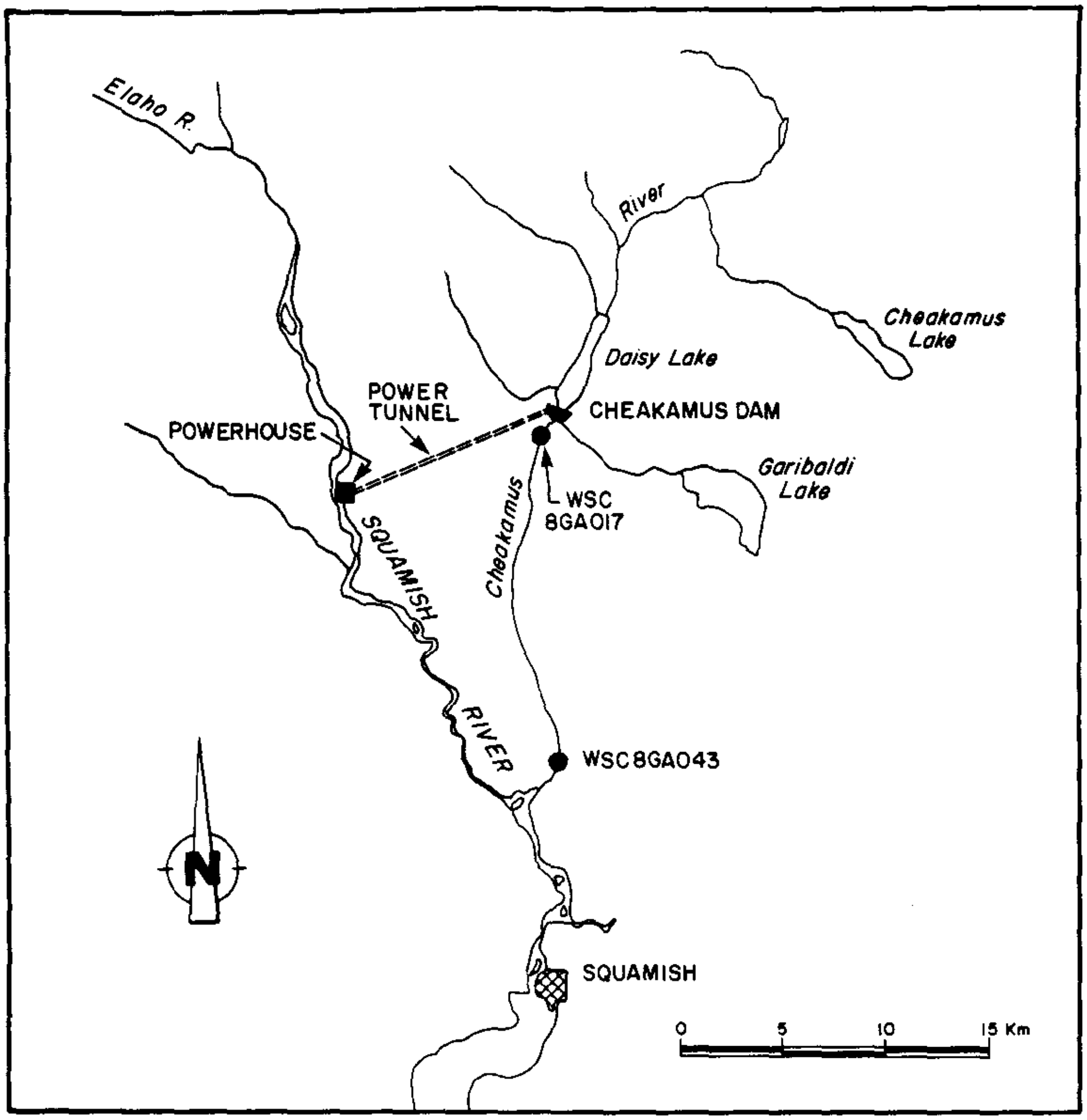
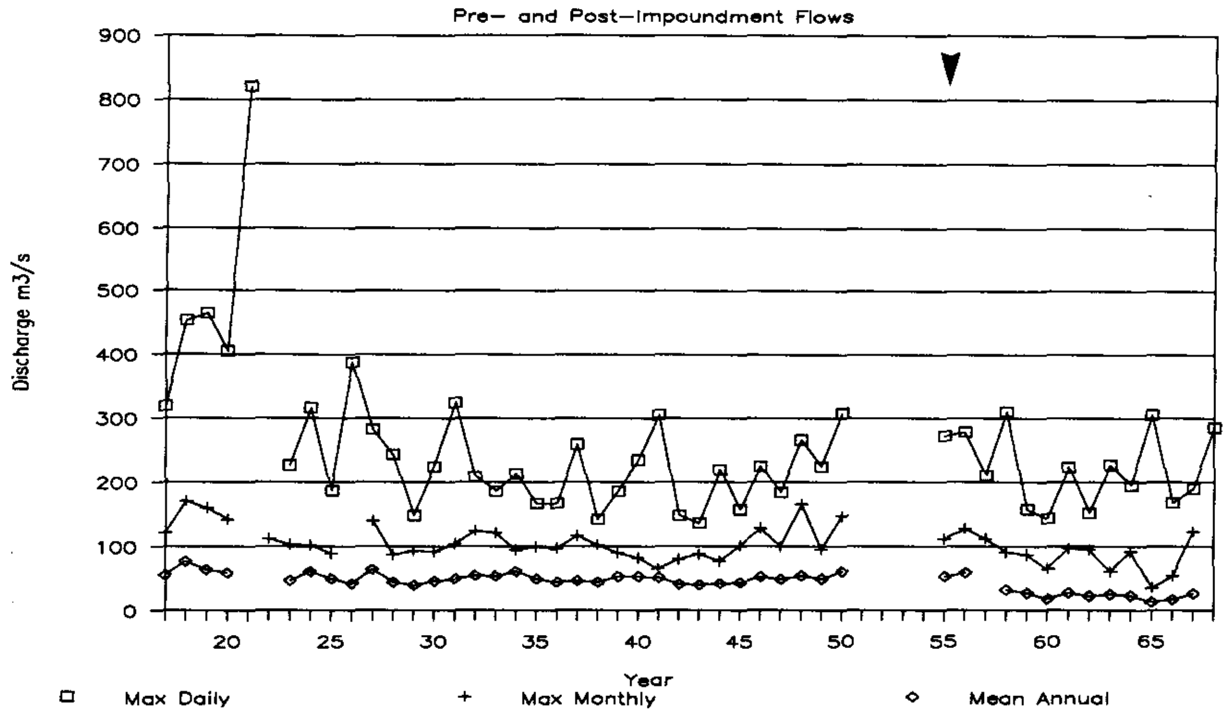


Figure 52. Location of the Cheakamus hydroelectric development.



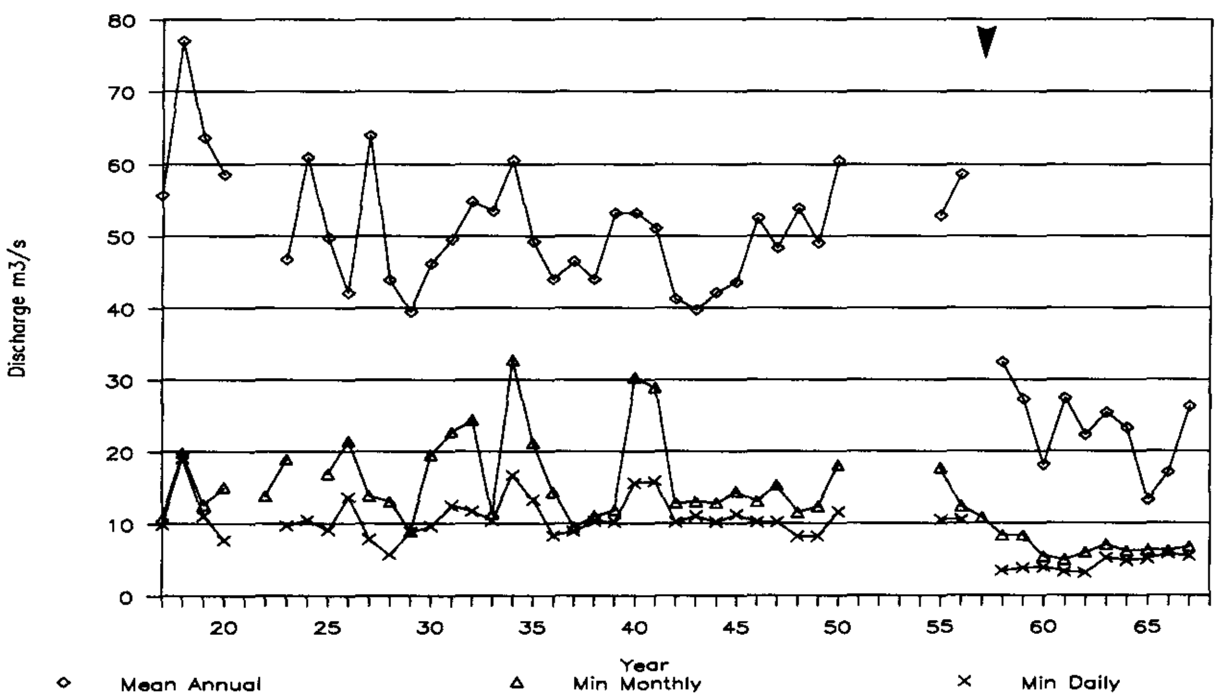


Figure 53. Pre- and post-impoundment annual flows in the Cheakamus River (WSC station below dam). Arrow indicates commencement of regulated regime. Data from Inland Waters Directorate (1988).

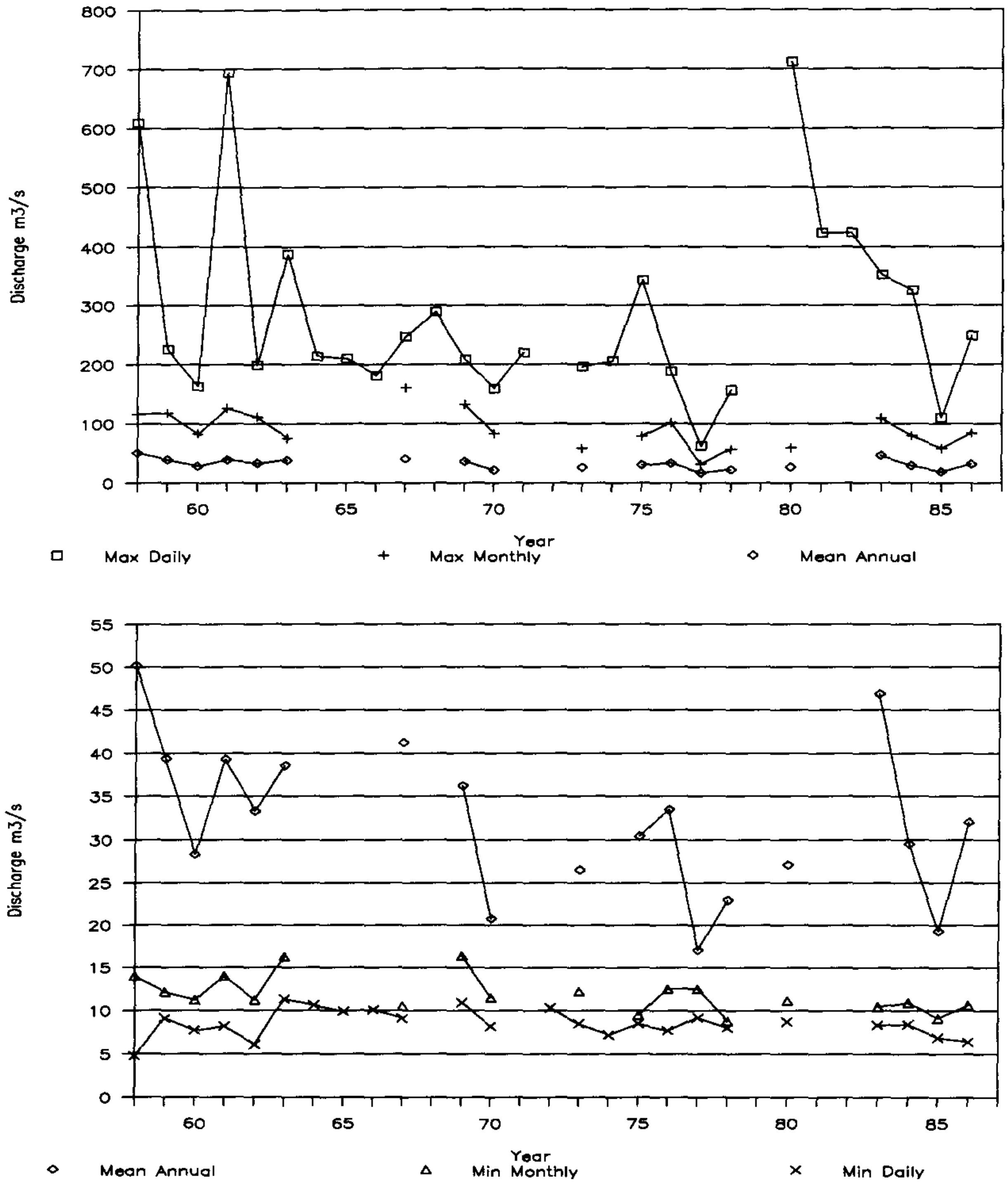
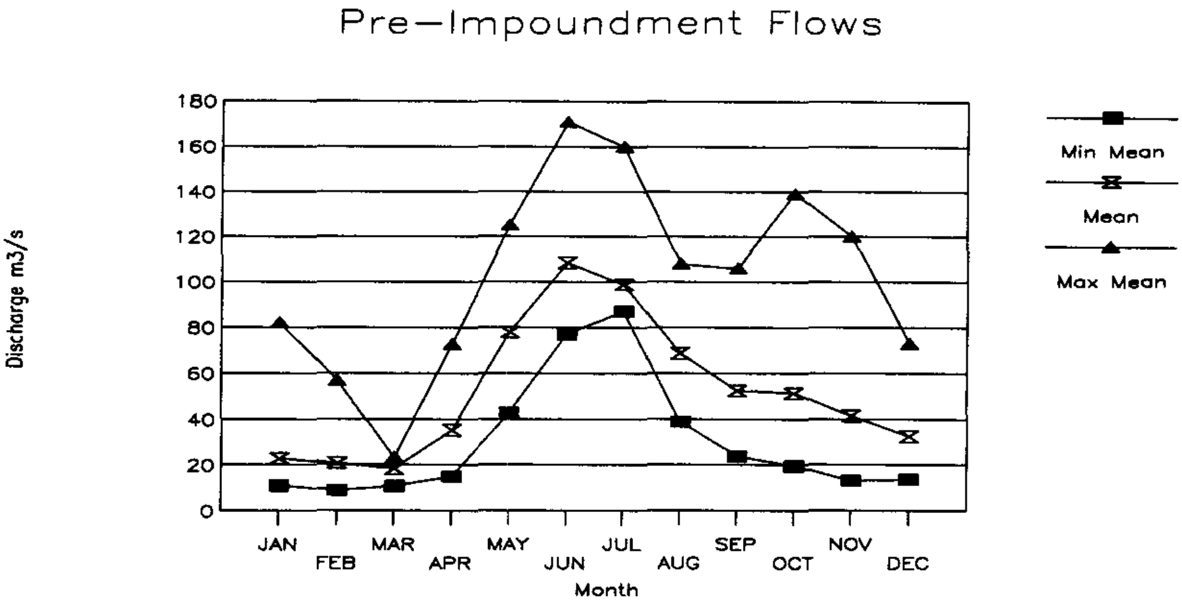


Figure 54. Post-impoundment annual flows in the Cheakamus River (WSC station near Squamish River confluence). Data from Inland Waters Directorate (1988).



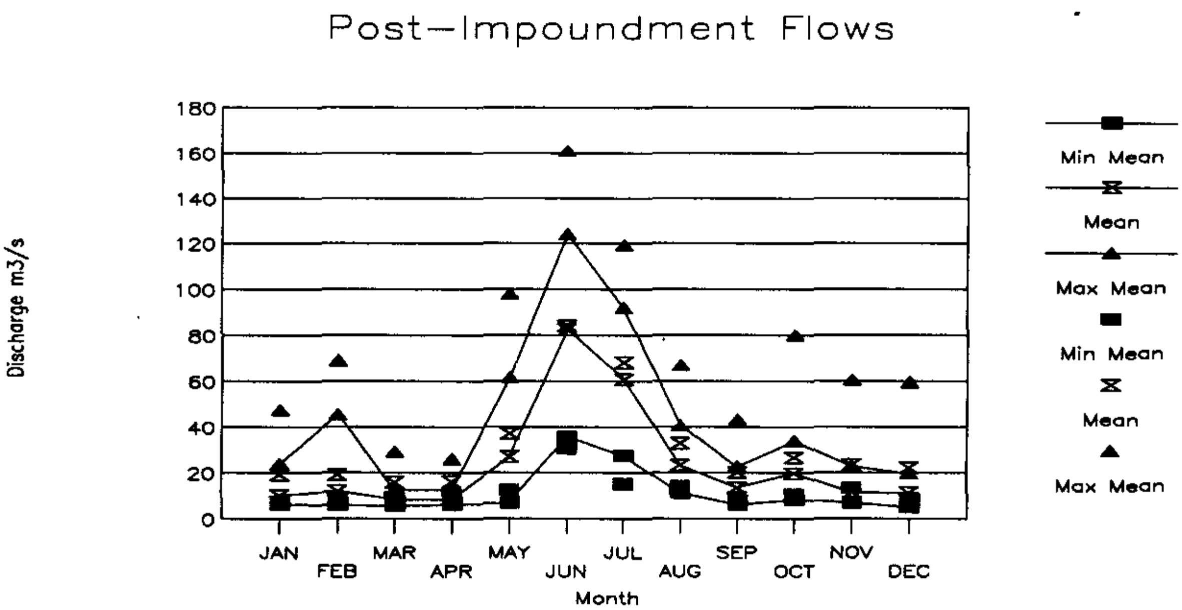
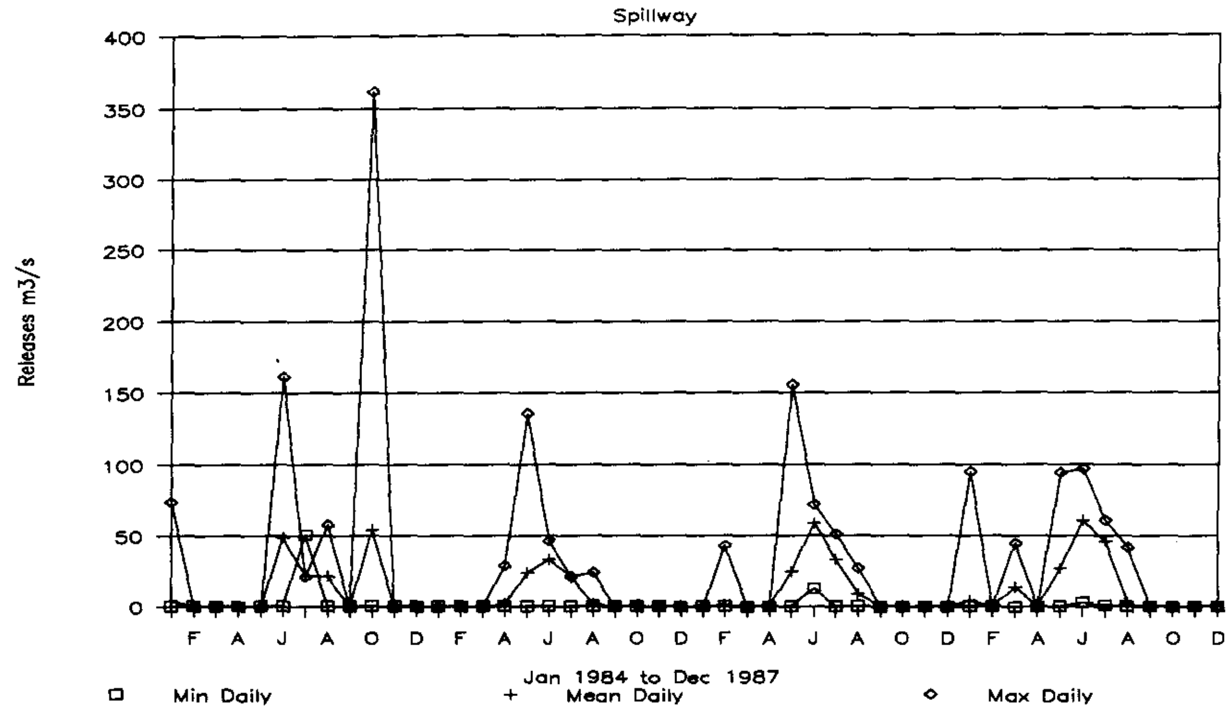


Figure 55. **Pre- and post-impoundment monthly flows in the Cheakamus River (joined points = WSC station below dam, separate points = WSC station near Squamish River confluence). Data from Inland Waters Directorate (1988).**



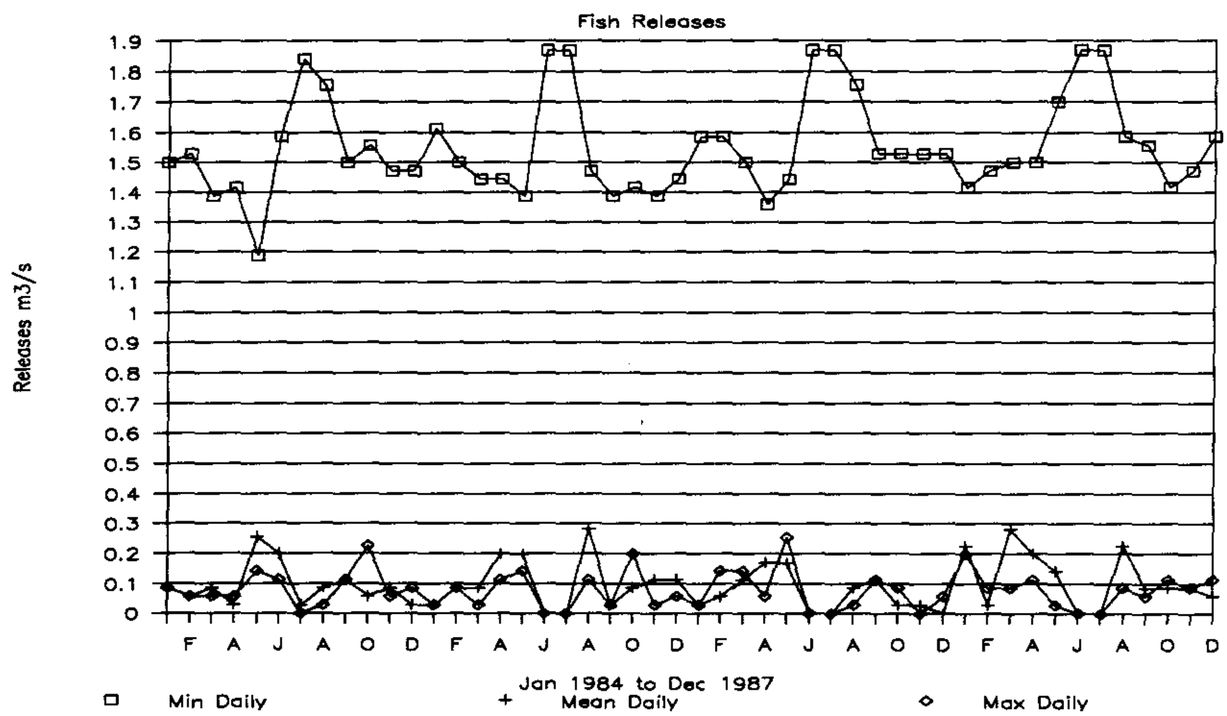


Figure 56. **Water releases through hollow-cone valve and over spillway at Cheakamus Dam 1984 - 1987. Data from B.C. Hydro, Operations Control Department.**

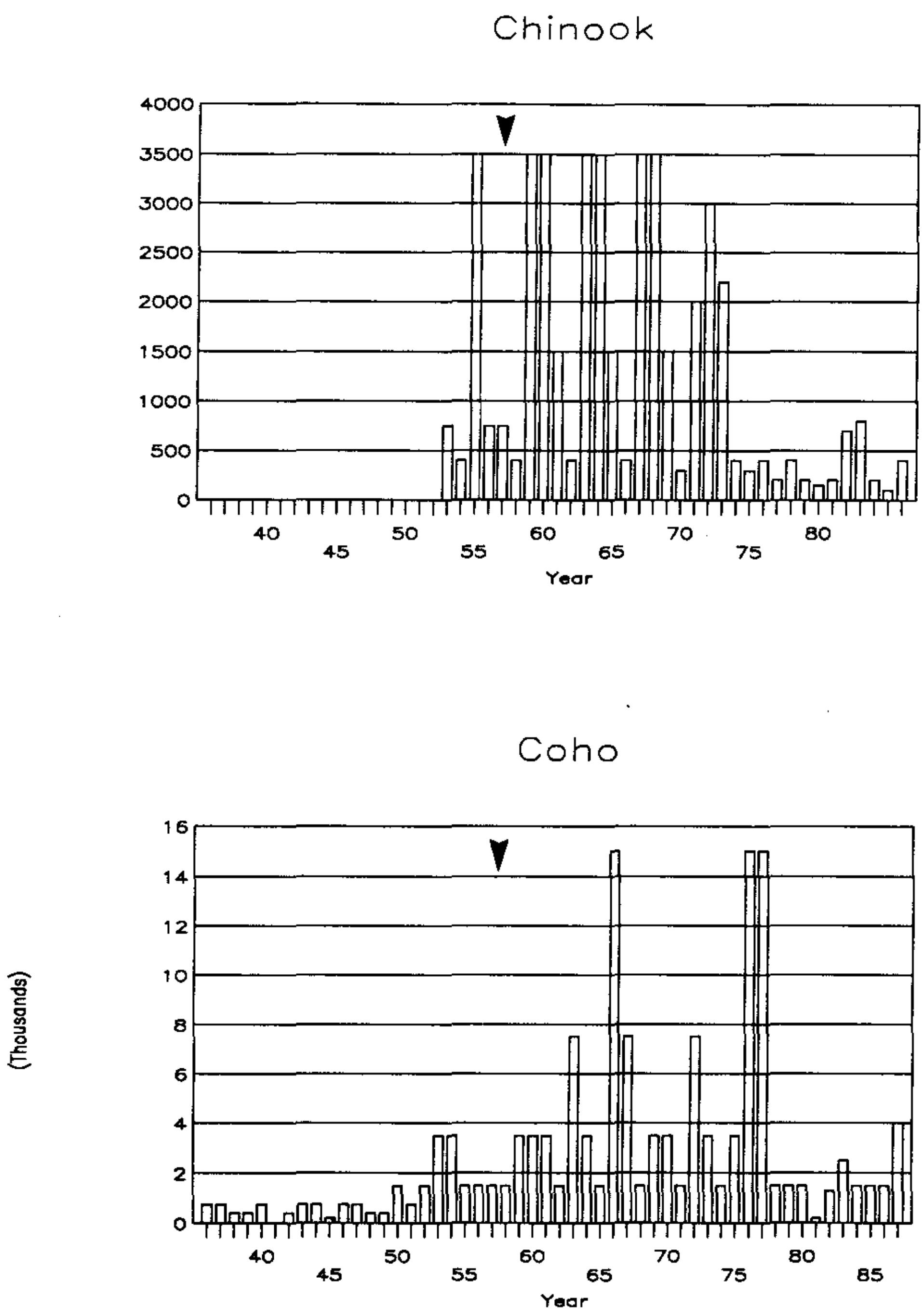
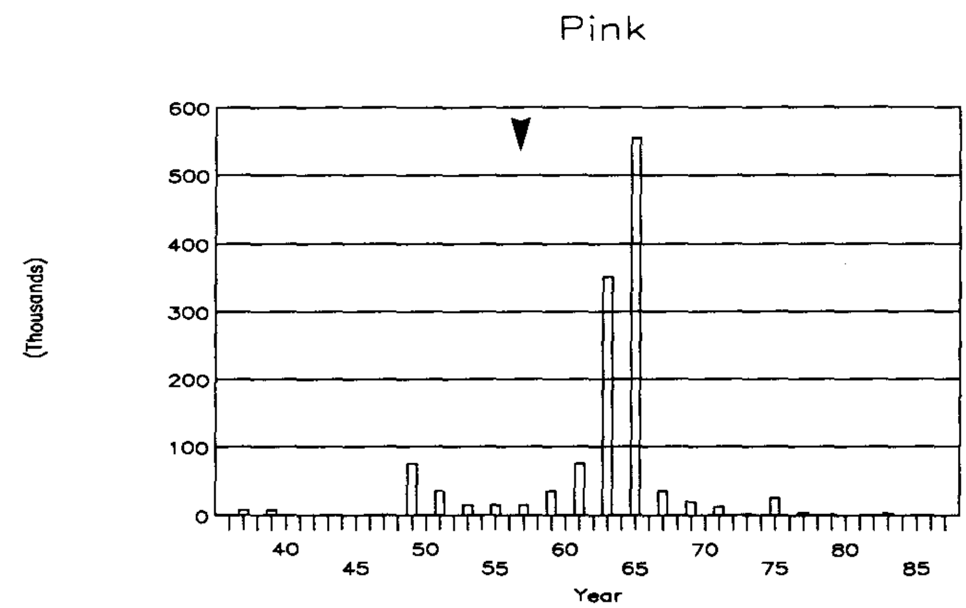


Figure 57. Salmon escapements to the Cheakamus River. Arrow indicates commencement of regulated regime. Data from Farwell et. al. (1987) and DFO escapement records.



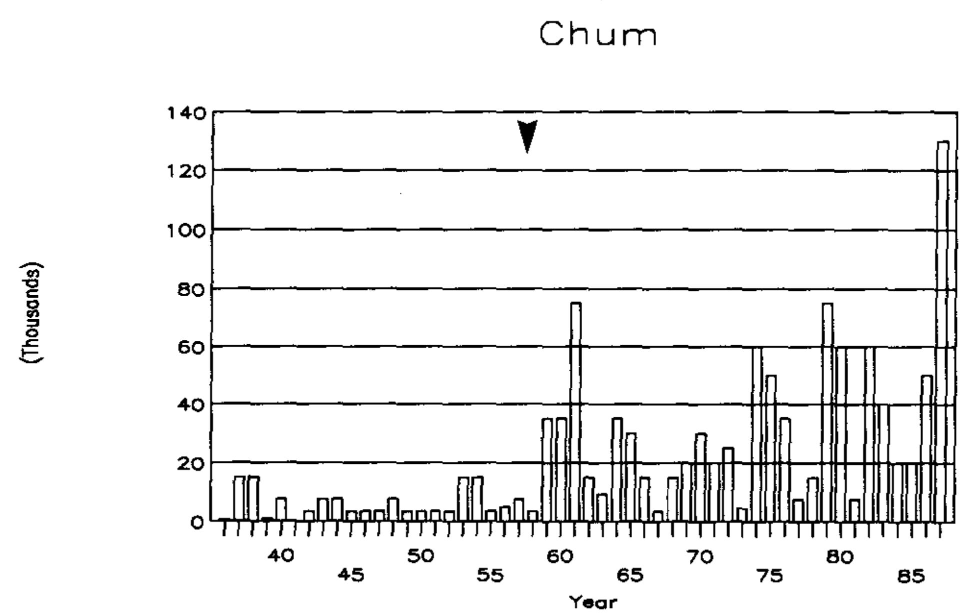


Figure 57. **Continued**

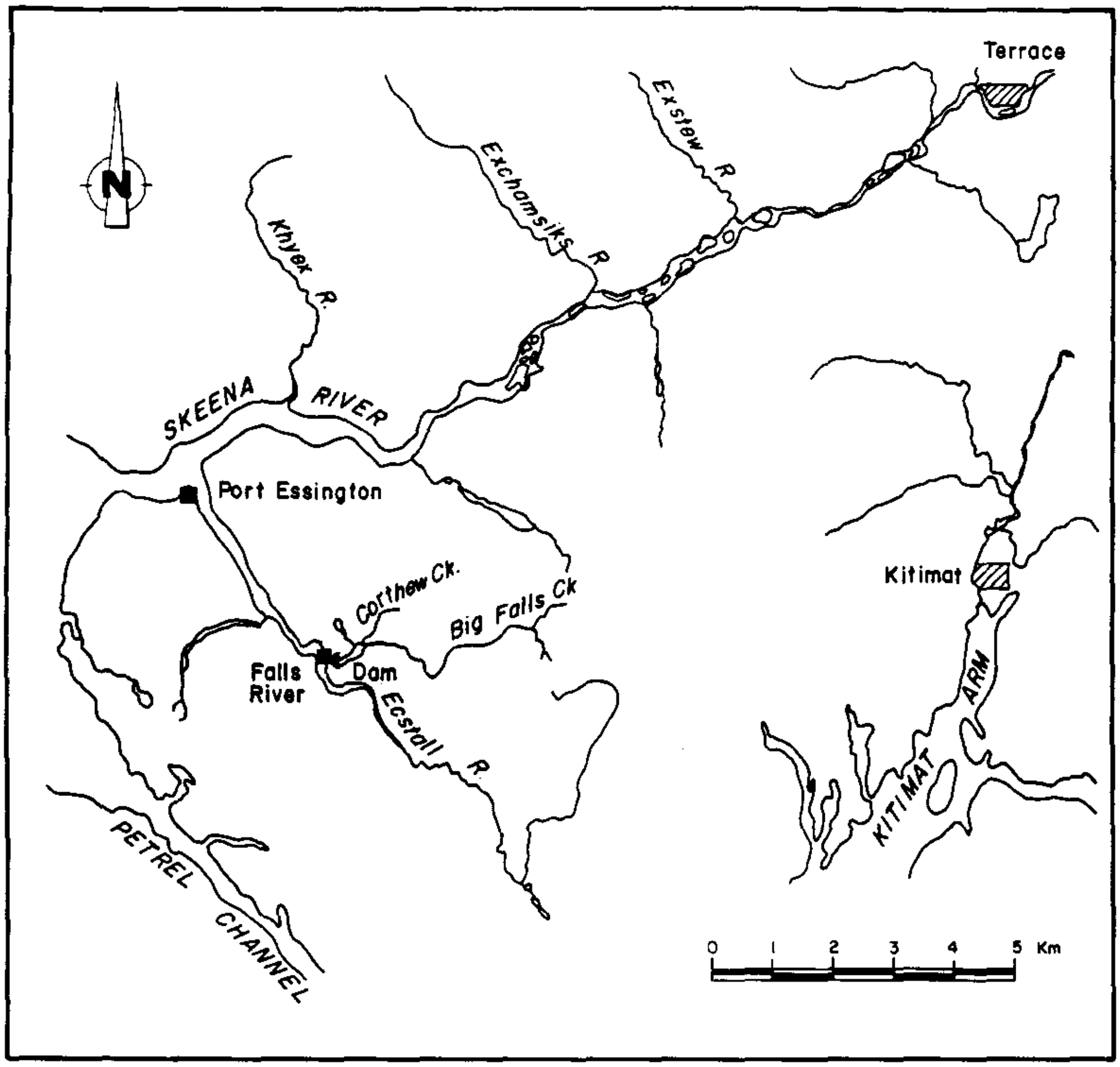


Figure 58. Location of the Falls River hydroelectric development.

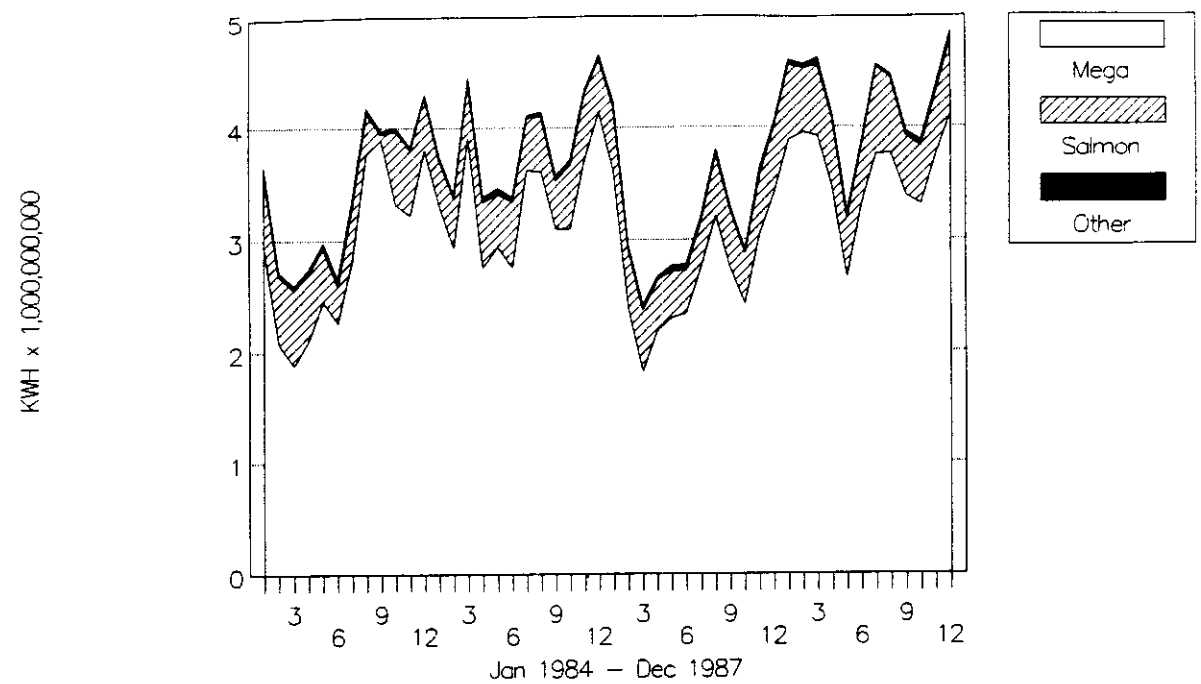


Figure 59. **Monthly electrical generation by mega-projects, by plants sited on salmon-bearing rivers, and by other plants (including thermal plants), 1984 - 1987. Data from B.C. Hydro, Operations Control Department.**

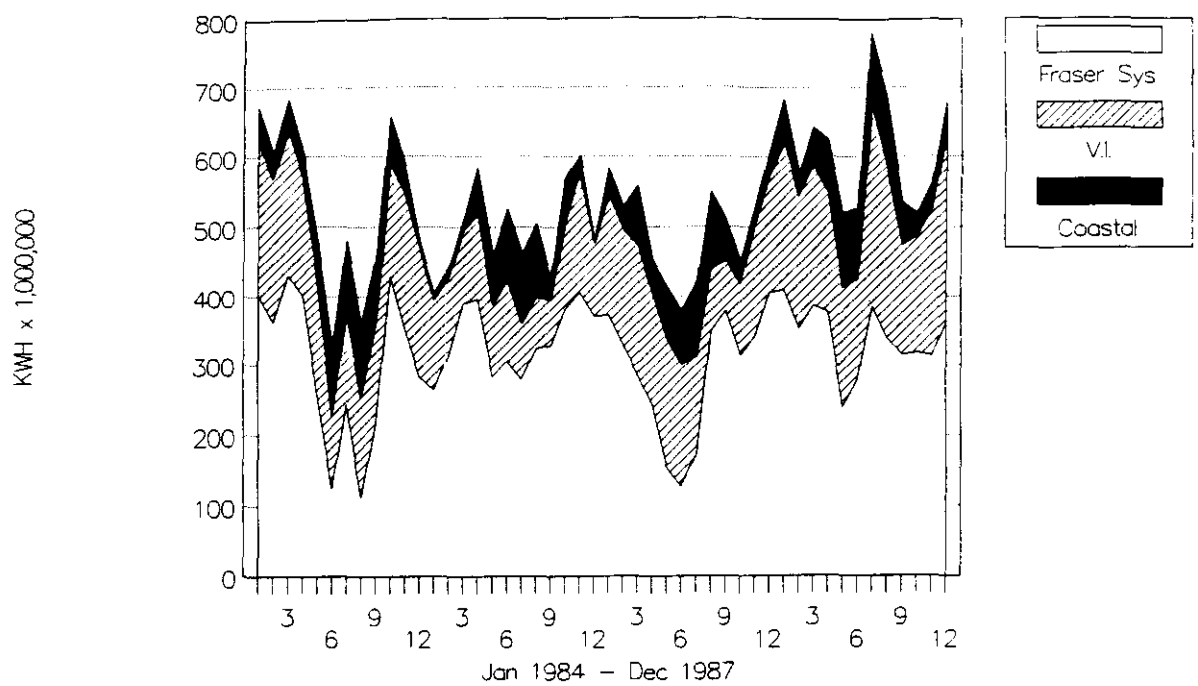


Figure 60. Monthly electrical generation by hydroelectric plants sited on salmon-bearing rivers within the Fraser River system, on Vancouver Island and along the B.C. coast, 1984 - 1987. Data from B.C. Hydro, Operations Control Department.

APPENDIX

Constraints on the operations of Seton hydroelectric power plant to protect sockeye salmon runs are developed by DFO each year and submitted to B.C. Hydro for consideration and implementation. The most recently devised constraints (1990) are given here as examples of the application of long-term applied biological research and the types of regulation needed to address the impacts of operational hydroelectric plants.

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1 April to 20 July

1. Adjust the fish water sluice to provide overshot flow from 1 April to 30 June.
2. Clean the trashracks at the penstock intake on or about 1 April, 1 May and 1 June to minimize smolt impingement.
3. Advise Fishery Officer and Habitat Management Biologist at least 2 working days prior to each cleaning of trashracks.
4. Maintain a minimum spill discharge of 200 cfs at Seton Dam through the fishway and fishwater sluice from 1 April to 30 June, and increase to 400 cfs by 20 July.
5. Use the fishwater sluice and siphon spillways for discharging flows greater than 200 cfs except in emergencies when the radial gate spillway may be used.
6. From 1 April to 30 June operate the turbine at the most effective range of 40 to 42 MW only.
7. From 1 April to 30 June maintain constant discharge at the outlet of Seton Lake for the longest possible time during hours of smolt migration by:
   a. maintaining continuous plant operation until Seton Lake reaches the lowest permissable elevation,
   b. leaving the plant shut down until Seton Lake reaches the highest permissable elevation, and
   c. making all changes in spill and turbine operation as soon after 0800 hours as possible.

20 July to 31 May (for odd-year runs)

1. Minimum spill discharge to be 400 cfs through the fishway and fishwater sluice operated in the undershot condition during the expected adult sockeye salmon migration period 20 July to 15 November.
2. During the sockeye migration periods 20 July to 31 August and 28 September to 15 November:
   a. the Cayoosh Creek component of the Seton-Cayoosh discharge to be limited by diverting Cayoosh Creek into Seton Lake and by spilling additional discharges at Seton Dam when required:
      i. the Cayoosh Creek component to be maintained below 20 percent during the Gates Creek migration from approximately 20 July to 31 August;
      ii. the Cayoosh Creek component to be maintained below 10 percent during the Portage Creek migration from approximately 28 September to 15 November;
      iii. Cayoosh Creek discharge at the gauge to be not less than 20 cfs.
   b. Seton generating plant to be operated at not less than 35 MW.
   c. Air to be injected into the draft tube during plant shutdowns to depress the draft tube surface to an approximate elevation of 589 ft.
   d. Radial gate spill to be restricted to 1000 cfs except when all siphons are operating.
3. Canal fish screens to be installed during the adult pink salmon migration period 15 September to 25 October and "speed - no load" plant operation during cleaning to be avoided.
4. Spill after completion of the sockeye migration to be not less than 200 cfs.
5. Spill during pink salmon spawning and incubation 15 September to 31 May to be not more than 2000 cfs except under emergency conditions.
6. Spill during pink salmon incubation to be not less than one-half of the spill during pink salmon spawning.

APPENDIX (CONTINUED)

20 July to 31 May (for even-year runs)

1. Minimum spill discharge to be 400 cfs through the fishway and fishwater sluice operated in the undershot condition during the expected adult sockeye salmon migration period 20 July to 15 November.
2. During the sockeye migration periods 20 July to 31 August and 28 September to 15 November:
   a. the Cayoosh Creek component of the Seton-Cayoosh discharge to be limited by diverting Cayoosh Creek into Seton Lake and by spilling additional discharges at Seton Dam when required:
      i. the Cayoosh Creek component to be maintained below 20 percent during the Gates Creek migration from approximately 20 July to 31 August;
      ii. the Cayoosh Creek component to be maintained below 10 percent during the Portage Creek migration from approximately 28 September to 15 November;
      iii. Cayoosh Creek discharge at the gauge to be not less than 20 cfs.
   b. Seton generating plant to be operated at not less than 35 MW.
   c. Air to be injected into the draft tube during plant shutdowns to depress the draft tube surface to an approximate elevation of 589 ft.
   d. Radial gate spill to be restricted to 1000 cfs except when all siphons are operating.
3. Spill after completion of the sockeye migration to be not less than 200 cfs.